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Innovation and politics: How the revolution affected the Cuban patent network, 1947–1976

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ABSTRACT

This study investigates how the Cuban Revolution of 1959—a shock that marked the country's transition from a capitalist to a socialist economy—reshaped the structure and dynamics of Cuba's innovation system between 1947 and 1976, with effects that still endure today. Drawing on historical patent data and social network analysis, the paper examines shifts in innovators' connectivity, clustering, and centrality, offering new insights into the long-term effects of institutional and geopolitical changes on innovation and economic trajectories, particularly in developing economies. The analysis reveals i) the dominant role of U.S. companies, especially in the pharmaceutical and chemical sectors during the 1950s; ii) the impact of the revolution's structural changes on the decline of patent activities and the attrition of the collaborative network; and iii) the subsequent emergence of innovation paths fostered by state-led initiatives and new international collaborations. The results underscore the key and evolving role of both Cuban public institutions and U.S. foreign policy, the resilience of central actors in the patent network—including several U.S. corporations that continued protecting their inventions despite the trade embargo—and the relative success of domestic initiatives in healthcare and pharmaceuticals. However, the findings also demonstrate how innovation ties became geographically concentrated after the revolution, as the international relationships of the island shifted. Overall, this research contextualizes contemporary debates on structural change and innovation dynamics regarding the role of public/private institutions, the implications of intellectual property rights, the importance of collaboration and absorptive capacities, or the influence of geopolitical realignments.

1. Introduction

Although Cuba was neither a developed economy nor a technological leader, during the last quarter of the nineteenth century and the first decades of the twentieth century it experienced a noteworthy advancement in specific technical domains, namely those related to the sugar industry and connected activities, including mass production technologies and modern central factories (Dye, 1998). Long before 1898, Cuba—still a Spanish colony—had been the recipient of significant technology transfer and skilled migration from France, Britain, and the United States (Curry-Machado, 2009; Pretel and Fernández-de-Pinedo, 2015). After Cuban independence, this process led to an increasing U.S. political, economic, and technological influence that boosted direct investments. Hence, during the first half of the twentieth century, many U.S. companies, engineers, and other staff established themselves in Cuba, transferring to the island part of their physical and intangible assets in key economic activities, such as agribusiness, public utilities, or the chemical sector (pharmaceuticals, rubber, etc.) (CIEM, 1984, p. 3).

Despite the relative technological development experienced during these decades and the expansion of innovation processes in certain industries, the country still had significant problems. A welfare state was never realized in Cuba, with large sectors of the population marginalized, without access to universal education or health care, and in a context of increasing corruption, poor administration, and fiscal irresponsibility, issues that worsened with the Batista dictatorship from 1952 (Thomas, 2003). These conditions gave rise to social unrest, several guerrilla campaigns, and, eventually, the Cuban Revolution,

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with Fidel Castro entering Havana and gaining control of the entire island in January 1959. This process triggered a profound structural shock that set off systemic transformations across the country's economic, social, and institutional spheres. The combination of socialist transition, close alignment with the USSR, and escalating conflict and economic blockade from the United States deeply shaped Cuba's development path and the evolution of its national innovation system (NIS) throughout the following years.

Thus, Cuba's shifting political and economic scenario represents a fascinating case study within the NIS framework, as it combines long-standing innovation attitudes, severe external constraints, institutional reforms, and deep structural changes (Freeman, 1995, 1987; Lundvall, 1992). Given that innovation dynamics can be significantly shaped by both internal and external shocks (Aarstad and Kvitastein, 2021; Soluk, 2022), the Cuban experience offers a unique opportunity to examine the consequences of the 1959 revolution—which fundamentally transformed Cuba from a colonial capitalist environment to a socialist economy—on its NIS. In particular, the main objective of this work is to analyze how such a drastic institutional shift has affected the collaborative behavior of patentees and inventors, providing critical insights into the resilience (or adaptability) of patent networks and, in general, into the impact of structural changes on its topology (Callaway et al., 2000).

To examine these dynamics, we build on original historical data extracted from the official Cuban intellectual property rights (IPR) registry before and after the revolution (1947-1976), which we study through social network analysis (SNA) methodologies. Using patent records as a proxy, we construct the Cuban innovation networks for five sub-periods and examine their statistical and topological properties—such as average degree, component size, and openness—complemented by sectoral and geographical indicators. This multi-dimensional approach allows us to capture how structural shocks reshape collaborative dynamics, innovation hubs, and flows of technical knowledge. In this manner, rather than merely assessing whether the Cuban innovation system collapsed or endured, we explore broader analytical topics: How do innovation systems adapt—or fail to adapt—under abrupt structural changes? What role do legacy infrastructures, geopolitical relationships, IPRs, and historical dependencies play in shaping innovation trajectories? And crucially, to what extent can radical institutional reforms and policy intervention redirect innovation and economic dynamics to enhance long-term technological sovereignty and economic resilience?

The analysis reveals that, before 1959, Cuba's patent network exhibited notable development, albeit under a strong U.S. influence. The system displayed topological features characteristic of relatively mature innovation structures, with steady expansion in both the number of actors and components, as well as improvements in key network metrics such as degree and betweenness centrality. Much like the broader economy, this growth was structurally dependent on a small group of major U.S. corporations (e.g., *American Cyanamid Company*), concentrated in a few strategic sectors—primarily pharmaceuticals and other chemicals. This trend underwent a dramatic shift following the Cuban Revolution, marked by a sharp reduction in the network's size and significant topological reconfigurations. By 1965, this attrition culminated in a fundamental transformation of the patent network, where many Cuban inventors ceased their activities and almost all U.S. patentees (previous drivers of the system) came to a halt. However, the results also reveal a progressive network reorganization based on some green shoots after the revolution, particularly in areas that received government support, such as pharmaceuticals and other chemicals together with the sugar and machinery sectors. We discover the formation of relatively large and active components, primarily driven by Cuban public institutions (e.g., *Universidad de la Habana* or *Centro Nacional de Investigaciones Científicas*) or big chemical and pharmaceutical companies from countries other than the United States (e.g., *Hoffmann - La Roche & Co. A. G.* or *Farbenfabriken Bayer, A. G.*), that later led Cuba to achieve some success in innovation—albeit industry-specific—during the last third of the twentieth century (Bianchi et al., 2020; Perez Villanueva and Albizu-Campos Espiñeira, 2023).

This transition provides an empirical vantage point to examine the systemic implications of public versus private drivers of patent activity—an issue of growing interest in the literature on structural change and technological development (Castelnovo, 2022). Moreover, it sets the context for evaluating how IPR changes can influence knowledge appropriation and, therefore, restructure collaboration under new public paradigms, consistent with recent insights on the role of patent protection in enabling or constraining innovation intensity (Bondarev, 2018; Viglioni et al., 2023). This also opens the door to further research on, first, the economic consequences of an unbalanced development of a NIS, because when the success of innovation remains confined to a specific sector—often sustained by public intervention—and fails to diffuse more broadly, long-term economic growth may be equally compromised, as seems to have occurred in Cuba, especially after the collapse of the Soviet Union (Gao et al., 2024; López-García et al., 2011); and, second, on the importance of absorptive capacities in structurally constrained contexts, where the ability to internalize and reorient foreign knowledge becomes a key factor in sustaining innovation under geopolitical realignment (Castellacci and Natera, 2016; Li and Du, 2025). Indeed, the study exemplifies the critical influence of geopolitics and international affairs on the development of NISs, a topic that has recently elicited growing concern in the economics of innovation (Chatterji and Murray, 2025; Góes and Bekkers, 2022). Finally, by exploring sectoral and geographical patent activity before and after the revolution, the work provides historical context for the expanding body of academic studies on Cuba's contemporary scientific and technological performance as well as its collaborative capacities (Díaz Pérez et al., 2018; Guzmán-Sánchez et al., 2018; Perez Villanueva and Albizu-Campos Espiñeira, 2023; Perez-Riverol, 2020; Ronda-Pupo, 2021).

In general, understanding how structural changes affect innovation processes is crucial not only for evaluating these previous issues but also for reflecting on the design of policies that enhance the resilience and adaptability of innovation systems, especially in the face of systemic disruptions. In fact, the Cuban case suggests two key insights: first, the fundamental role of public environments and international affairs—surpassing that of market forces—in shaping long-term innovation trajectories and structural constraints; and, second, the intrinsic importance of specific topological configurations of collaboration in the evolution of innovation networks, wherein an optimal NIS should balance large, well-established hubs with smaller, agile actors, reducing overdependence on centralized structures while still leveraging economies of scale and scope. To explore this complex interplay in depth, the next sections are organized as follows: Section 2 explains the Cuban IPR regime and describes the patent database, periodization, and basic statistics. Section 3 presents the analytical framework: research questions, hypotheses, and SNA methods and measures. Section 4 provides the results and findings on the evolution of Cuban patent networks, while Section 5 concludes with the academic and policy implications.

2. Cuban IPRs, the patent database, and descriptive statistics: advantages and limitations

2.1. The Cuban patent system

To manage IPRs, Cuba developed one of the first patent systems in Latin America to both protect inventions and introductions of technology, mimicking the institutional idiosyncrasy of its metropolis. In 1833 and 1880, Spain extended to Cuba, Puerto Rico, and the Philippines its 1826 and (part of) 1878 domestic patent laws, designed to safeguard invention activity but also to foster industrialization and technology transfer.[1] Due to the geographical distance, Cuba had its own local granting office, where approximately 3,000 patents were registered during the nineteenth century (Fernández-de-Pinedo et al., 2010). After the 1898 Spanish-American War, the United States occupied Cuba and tuned the patent regime to match their economic interests. Between 1899 and 1901, the U.S. military governor passed several orders that finally extended U.S. patent and trademark rights to the island, with the only requirement of filing a certified copy of the original document.[2] Even after the formal independence of the Republic of Cuba in 1902, the United States maintained significant control of the island through the Platt Amendment, overseeing the country's economy and international affairs (Sanchelima, 2003).[3] In 1936, a new Cuban IPR law was passed, inspired by the Spanish Law on industrial property of 1929, which regulated all IPR modalities under a single framework: patents, trademarks, trade names, industrial designs, and motion picture films.[4] In any case, before and after 1936, U.S. IPRs flooded into Cuba, creating a network of patent holders, inventors, and businessmen, with an ever-increasing presence during the 1940s and 1950s.

The shock caused by the Cuban Revolution in 1959 also affected patent practices. Contrary to what occurred in the Soviet Union—where Lenin abolished patents in 1919 by passing a new law to certify invention authorship (Burrus, 1962; Plasseraud and Savignon, 1986)—Castroism maintained the 1936 Cuban patent law (and its 1956 regulations) with only minor amendments.[5] In 1959, the new government introduced compulsory exploitation licenses—already common in other countries—aimed at preventing commercial monopolies without working the invention domestically; and in 1960 it allowed the state to take over certain economic activities previously carried out by private entities, which would have encompassed the management of their IPRs. This formed part of a broader economic and political agenda that affected the treatment of IPRs by discouraging domestic private patenting in favor of a public R&D system. Under the new order, the primary national objective regarding invention activity and patent registration changed from profit-making to the preventive protection of ideas, a transition that was ultimately reflected in the more socialist-oriented legislation enacted in 1983.[6]

Nevertheless, Cuba has always guaranteed the concession of patents, because—in an increasingly tense context with the United States and despite closer rapprochement with the USSR—this policy remained strategically important for further collaboration with Western economies, where IPRs served as standard means of protecting inventive activity.[7] Beyond the empirical period analyzed here, Cuba's 1995 WTO accession required legal reforms aligning its patent system with international standards, particularly for pharmaceuticals and other chemical products.[8] Patent management would subsequently become central to Cuban technological exports; scientists leading key research institutions have acknowledged the Cuban patent system's value for protecting innovations internationally, with more than 1,700 patents granted to Cuban institutions and researchers since the 1990s (Lage Dávila, 2024). New legislation in 2012 and associated regulations in 2018 further consolidated this framework incentivizing inventors to share in the benefits of patent exploitation.[9]

Therefore, a long-standing and continuous patent record exists in Cuba, spanning both before and after the revolution. As the main objective of this paper is to examine the impact of the 1959 institutional shock on the Cuban inventor/innovator collaboration patterns, the patent registry serves as the only available proxy for constructing such networks across the different periods of analysis. Undoubtedly, patents have well-known limitations, as they do not capture all innovation activities and, particularly in this case, were affected by the radical institutional change. The revolution was an inflection point in the Cuban innovation system in many respects, shifting priorities towards public science, state intervention, and centrally directed research efforts. Patent-based indicators may therefore capture different phenomena in each period, and this should be considered when comparing network structures across the pre- and post-revolutionary stages. However, as stated above, Cuba not only maintained the previous patent system after the revolution but also took strategic advantage of it in the new context. On the other hand, alternative proxies—such as R&D expenditures—are scarce and difficult to systematize, and they also suffer from drawbacks comparable to those of patents (Acs et al., 2002; Griliches, 1990; Schmookler, 1966).

Moreover, relying on patents and SNA techniques means that non-patented forms of innovation and collaboration remain outside the scope of this study. While, generally, registered and non-registered innovations tend to be correlated, this may constitute a relevant limitation in the context of developing economies, where informal and non-patented innovation may be substantial. Although collaboration outside the patent system exists in any country and at any point in time, in the case of socialist Cuba non-patented scientific, technical, and educational cooperation with the USSR and COMECON countries increased significantly after 1959, and this cannot be captured with the

[1] *Real Cédula de 30 de julio de 1833* and *Real Decreto de 14 de mayo de 1880* (Sáiz, 1996, pp. 64–68 and 101–102).

[2] See "Patent and Trade Mark Rights in Cuba" and "Registration of United States Patents and Trade Marks in Cuba" in *Scientific American*, vol. 83, November 24, 1900, p. 327 and December 8, 1900, p. 355 respectively. See also "Protection of Patent and Trade-Mark Rights in Cuba, Isle of Pines, and the Island of Guam under Military Authority of the United States", *Official Gazette of the United States Patent and Trademark Office*, vol. 96, Part 2, August 20, 1901, p. 1436.

[3] The Platt Amendment was repealed and replaced with a new Cuban-American Treaty of Relations in 1934, under the Roosevelt 'Good Neighbor Policy' (Pretel, 2022, p. 279).

[4] *Ley de la Propiedad Industrial de la República de Cuba, Decreto-Ley 805, Gaceta Oficial de la República de Cuba* (GORC) (edición extraordinaria), April 11, 1936. The Regulations for this law were passed by the *Decreto-Ley 209*, GORC (edición extraordinaria), February 7, 1956.

[5] *Ley 618 de 27 de octubre de 1959* and *Ley 914 de 3 de enero de 1960* (Sánchez Roca, 1960, 1961).

[6] *Decreto-Ley 68,* GORC (edición extraordinaria), May 14, 1983.

[7] One example is in Brundenius (1987), who examines the key role of patent rights during the late 1960s and early 1970s, when Cuban engineers designed an advanced sugar cane harvester—the *'Libertadora'* (Liberator)—that the incipient Cuban capital goods industry was unable to mass-produce. They patented the machine and licensed the patent rights to the West German firm *Claas Maschinenfabrik*, with whom they collaborated in its large-scale manufacturing. In exchange for the patent rights, the firm allowed Cuba to import the machines at a subsidized price. This demonstrates that, besides the USSR—with whom Cuba also collaborated on other harvester designs—the government was equally interested in further collaboration with Western countries, for which patents were necessary.

[8] *Decreto-Ley 160*, GORC (edición extraordinaria), June, 10 1995.

[9] The 2012 patent law in *Decreto-Ley 290/2011*, GORC (edición extraordinaria), April 16, 2012. The regulations in the *Decreto 342/2018* and the new procedures in the *Resolución 151/2018 del Ministerio de Ciencia, Tecnología y Medio Ambiente*, both published in the GORC (edición extraordinaria), August 10, 2018.

present methodology. Further research based on case studies or alternative data sources would be necessary to explore these dimensions of the Cuban innovation system.

2.2. The patent database

To analyze the Cuban innovation landscape before and after the revolutionary shock, we developed a relational database using the information available at the Cuban patent gazette (*Boletín Oficial del Ministerio de Comercio*, hereinafter referred to as BOMC), which served as the official channel for the periodic publication of patents registered in Cuba.[10] The first step was to process the collections of BOMCs from 1946 to 1979 using OCR algorithms and to index the texts with basic natural language techniques.[11] Yet, the quality of the historical BOCMs was poor, causing the OCR recognition accuracy to fall below 80% on average, with some volumes yielding higher rates and others very low ones (see Figs. A1 and A2 in the Appendix A). This required further processing, involving both automatic corrections for systematic OCR errors and manual editing of the worst results until all the mistakes were eliminated. The second phase consisted of creating an entity-relationship model (Fig. A3) and the database structure in a PostgreSQL server instance (Fig. A4), where the indexed texts were stored in distinct tables and fields. This process led to the first version of the database, which still required additional work to be completed. The third and final step involved designing and developing a web platform (see Figs. A5, A6, and A7) to enable editing of the database through bulk correction routines, combined with the research team's meticulous, time-consuming inspection of each patent, the original BOMCs, and international patent databases (USPTO, Espacenet, Google Patents, etc.) in order to complete the records and correct as many errors as possible.

The procedure was robust, with virtually all the patents listed in the BOCMs incorporated into the database, together with all the data available in the official gazettes plus complementary information obtained from the aforementioned international sources (given that many of the Cuban patents cited 'priorities', i.e., the original patents filed abroad). This allowed us to incorporate missing data, for instance on the inventor/patentee name/denomination or place of residence. A fundamental procedure was to correctly disambiguate inventors, assignees, and patent agents, listing individuals and companies and detecting duplicate names caused, for example, by minor typographic errors in the original sources. This required a substantial effort, as it is a critical step for a precise identification of the nodes and their associated edges when constructing the networks. We also geopositioned patent applicants by matching their place of residence with the corresponding latitude/longitude coordinates in geographic databases such as *GeoNames*,[12] with manual supervision of any errors. Additionally, as the BOCM include the patent classification according to the 1936 Cuban technical nomenclator (see Fig. A8), we generated a concordance table to match the nomenclator codes to economic sectors, following Schmookler's (1966, 1972) system for identifying the main industry or activity in which the new technology or product could increase productivity.

The final result is a comprehensive, well-structured database containing all the basic information on 10,046 Cuban patents (number, invention, dates, priorities, technical classification, economic sector, and IPR agent) together with detailed data on 9,765 disambiguated innovators (inventors and assignees) from 1946 to 1979. Table 1 summarizes the core variables included in the database, from which we generated the patent-actor interaction dataset and subsequently the adjacency matrices used to construct the co-patent networks for each sub-period of the study.

Table 1
Database information related to patent and innovator characteristics, Cuba (1946-1979).

	Information	Description
Patent	*Number*	Cuban Patent Number
	Type	Invention / Introduction / Deposit
	Date	Expedition Date
	Priority	Date, Country, and Number of Priorities
	Nomenclator	Cuban Patent Technological Classification
	Sector	Economic Sector
	Agent	Name, Location, Street, Latitude, and Longitude
Innovator	*Name*	Surname, Name / Denomination
	Juridical status	Individual / Firm / Organization
	Cuban Resident	Binary Variable (Y/N)
	Role in the Patent	Patentee / Patentee-Inventor / Inventor
	Place of Residence	Location, Province, Country, Latitude, and Longitude

Source: Sáiz et al. (2022).

A final note concerns the fact that this work does not include systematic international comparisons, which represents a boundary condition of the analysis presented in the following sections. We acknowledge that building comparable patent databases and networks for other countries during the same period under study—particularly those that underwent similar structural or institutional transformations or those in the Latin American and Caribbean region—would involve considerable effort and methodological challenges that fall outside the scope of the present work. Nevertheless, cross-national comparison remains a priority for future research, as it would allow for a more robust assessment of the specificities of the Cuban case.

2.3. Time windows

To study the evolution of the Cuban patent network, we use five six-year periods from 1947 to 1976. In doing so, we opt for a periodization strategy considering key sociopolitical events in Cuba. This segmentation results in the following windows: 1) 1947-1952, associated with a stage of development of Cuba under U.S. influence; 2) 1953-1958, covering the Batista dictatorship era; 3) 1959-1964, marking the initial years of the Cuban Revolution; 4) 1965-1970, which encompasses the post-Cuban missile crisis and second steps of Castroism; and 5) 1971-1976, characterized as the era of gradual transition to socialism in Cuba. For the sake of concreteness, although we report detailed results following the five-time windows, we structure our discussion considering three main phases. The first phase before the revolution covers the *Pre-Revolutionary* period and encompasses the first two windows (1947-1952 / 1953-1958). The second phase during Castro's shock will be termed the *Revolutionary* period, isolating the effects of the third window (1959-1964). Lastly, we consider the third phase after the revolution as the *Post-Revolutionary* period, consolidating the last two windows when analyzing the long-term effects of the revolution (1965-1970 / 1971-1976).

2.4. Descriptive statistics

To offer a complete and holistic view of the Cuban innovation system, it is necessary to draw on both domestic and foreign patents granted on the island. This follows established practice in the NIS literature, where innovation is conceptualized as an interactive process involving knowledge creation, diffusion, and absorption across geographical and institutional boundaries (Edquist, 2005; Freeman, 1995, 1987; Lundvall, 1992; Nelson, 1993). The key lies in focusing on how these processes affect the national economy, regardless of whether knowledge is created domestically or sourced/imported from abroad. In the Cuban case, foreign patents reveal the interest of actors

[10] From 1961, *Boletín Oficial del Ministerio de Industrias*; from 1967, *Boletín Oficial del Ministerio de la Industria Básica*; and from 1968, *Boletín Oficial del Registro de la Propiedad Industrial*.

[11] For OCR, mainly Tesseract (see https://github.com/tesseract-ocr/tesseract), and for text indexation Sphinx Search (see https://sphinxsearch.com/).

[12] See https://www.geonames.org/.

from third countries in securing property rights on the island, both before and after the revolution. This carries a range of consequences for the domestic side of the innovation system—from pure technology transfer embedded in patent documents, to foreign direct investments for commercializing or manufacturing patented products, to the enhancement of domestic capabilities for international knowledge absorption, and to potential blocking effects on domestic developments through IPR enforcement (Archibugi and Michie, 1995; Fagerberg and Srholec, 2008). We therefore aim to capture the full landscape of knowledge flows and interactions that shape innovation capacity at the national level. This will allow us to explore the distinct nature of collaboration dynamics before and after the 1959 revolution (including changes in the foreign origin of patented technologies, the development of new Cuban knowledge hubs, and related phenomena).

Fig. 1 depicts the distribution of patents registered in Cuba by the applicants' country of residence across the studied time windows. In the *Pre-Revolutionary* period (1947-1958), the number of records reflects an upward trajectory in innovative activity, primarily driven by a rise in patents involving U.S. applicants on the island. This landscape shifted radically during the *Revolutionary* period (1959-1964), as evidenced by the significant contraction in annual registrations, particularly in the number of patents involving Cuban applicants. In the *Post-Revolutionary* period (1965-1976), a further shrinkage of the patent system is observed, characterized by the disappearance of many U.S. patentees, leaving the innovation environment predominantly in the hands of other countries (mainly European) and local applicants (mainly state institutions). However, despite the political transition, U.S. actors did not completely vanish, especially between 1959 and 1964, during which they were still involved in over 600 patent applications. Even in the final period of analysis, amid the blockade, new U.S. firms entered the system. This reveals the complex dynamics between geopolitical tensions and economic interests, opening new research avenues for historians of politics, economics, and business.

Thus, this initial analysis, based on a simple patent distribution per country and year, shows that the revolution marked a turning point in the innovation ecosystem, with consequences that persisted for the next two decades and remain evident today.[13] To deepen in the character of this change, Table 2 presents the top actors in the Cuban system by patent counts and main sectors of patenting activities across the five time windows studied. As expected, the main actors prior to 1959 were U.S. corporations operating in pharmaceuticals and other chemicals, and extending patent rights to Cuba to monopolize the manufacture of these products and, especially, their commercialization on the island. Although several of these U.S. companies continued patenting after the revolution, they were replaced with European chemical and pharmaceutical firms, especially after 1965. Finally, Cuban institutions also led patent registration from 1965 to 1976 in pharmaceuticals and other chemicals, as well as in other key activities such as agriculture, sugar, tobacco, or mining.

After 1959, *Merck & Co, Inc.; American Cyanamid Company*; and *Miles Laboratories, Inc.* still registered patents. Several other U.S. companies were also active, particularly in the first period after the revolution, including *Norwich Pharmacal Company; E. I. Du Pont de Nemours & Company*; and *Chas Pfizer & Co Inc*. All these companies operated mainly in pharmaceuticals and other chemicals, protecting various kinds of compounds and drugs (with *E. I. Du Pont de Nemours & Company* focusing more specifically on herbicides for the agricultural sector). Their activity declined sharply after 1965 (only *American Cyanamid Company* and *Chas Pfizer & Co.* filed a few patents after that date), although there were new entrants, such as *Rohm & Hass Company; Chemical Construction Corporation*; and *AMAX Inc*. The first protected chemicals for agricultural use, while the latter two filed patents for advances in mining and metallurgy. All in all—and as stated above—this enduring activity demonstrates the strength and reach of U.S. multinational corporations and the complexity of the international relations, which warrants further research. A thorough analysis of the business history of these firms—their strategies, their evolution after 1959, and their resilience or adaptation to the new institutional environment—would be a valuable contribution to that field and related disciplines.

Regarding Cuban patentees, during the pre-revolutionary period they were mainly independent innovators (technicians, professionals, businessmen) and small companies, operating in low-tech activities—such as service-related goods—and filing much fewer patents per capita than the top U.S. actors shown in Table 2. More than 80% of these Cuban patentees were located in Havana, while only two other provinces—Matanzas and Santiago de Cuba—stood out with approximately 5% each. After the revolution, particularly from the 1970s, Cuban public institutions dominated the patent system, reflecting the changes that occurred in the country and the new scientific and technical policies. Yet, the share of patentees in Havana increased (89%), with Santiago de Cuba (3%) and the province of Villa Clara (3%) lagging far behind, which reveals an interesting phenomenon of knowledge concentration mainly around the new scientific institutions (that later on would be clustered into the well-known *West Havana Scientific Pole*) (Guzmán-Sánchez et al., 2018). Notwithstanding this agglomeration in Havana, further research could delve into the economic geography of innovation on the island. A detailed spatial mapping of patentees and inventors—which falls beyond the scope of this paper—could chart the territorial evolution of both resident and non-resident patenting before and after the revolution, thereby providing a richer picture of the regional dynamics of innovation in Cuba and its international connections, including the geography of links from specific regions of the United States and other countries.

3. The Cuban patent network: analytical framework, methodology, and SNA measures

3.1. Analytical framework, research questions, and hypotheses

This study is grounded in an SNA approach, with a specific focus on the structural configuration of innovation networks, which constitute a collaborative framework where diverse actors—inventors, entrepreneurs, firms, research institutions, or government bodies—converge to exchange knowledge, share expertise, and pool resources (Gilbert et al., 2001). Their significance lies in their ability to enhance the efficiency and effectiveness of innovation processes, facilitating the transfer of groundbreaking ideas and cutting-edge technologies (Acemoglu et al., 2016). By scrutinizing the dynamics of nodes and interactions within networks, we gain valuable insights into the structural aspects of the drivers of innovation, while also obtaining information on the socio-economic processes that underpin successful collaborative endeavors (Schilling and Phelps, 2007; Ter Wal, 2014). Thus, evaluating a network's capacity to adapt and persist (or, conversely, collapse) can shed light on how an innovation system reacts to shocks, technological disruptions, or structural changes in economic/political paradigms (Van Aswegen and Retief, 2020).

Furthermore, the analysis of network statistics and topological structures is key to understanding network dynamics: robust and interconnected networks foster knowledge dissemination, while weak and fragmented ones hinder the innovation process (Fleming et al., 2007). In this sense, several characteristics of innovation and patent networks have been studied from an evolutionary perspective, highlighting the importance of regional development in their trajectory (Lozano and Arenas, 2007; Tsouri and Pegoretti, 2021), examining historical divergences across countries (Andersson et al., 2019), or

[13] Between 1997 and 2008, an average of only 75 patents per year were registered in Cuba (Díaz Pérez et al., 2018, fig. 1), a figure that has declined further since 2012 (Perez Villanueva and Albizu-Campos Espiñeira, 2023, Fig. 2).

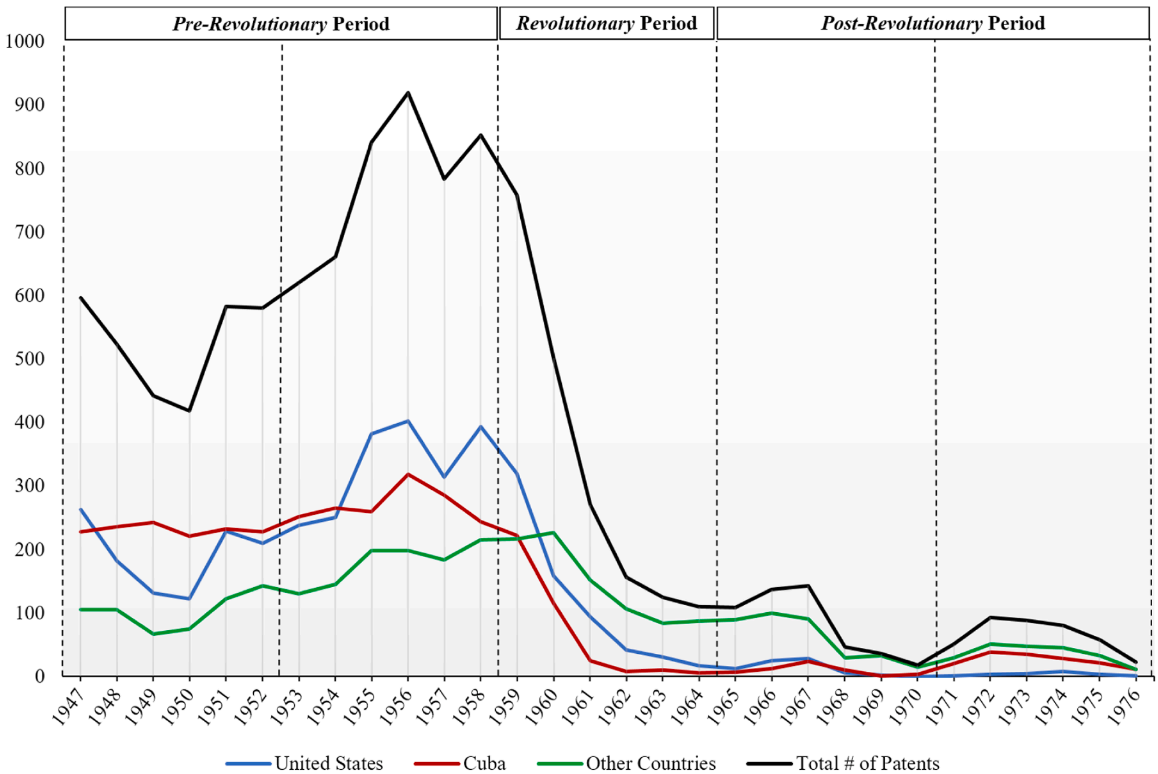

Fig. 1. Patent registrations by innovators' country of residence and by year, Cuba (1947-1976)
Note: Patents are counted by the country of residence of their applicants. Only when the innovators involved in a patent have different countries of residence they are counted once for each country, which occurs in only a small number of cases (see Section 4.5. on homophily).
Source: Sáiz et al. (2022).

studying the factors promoting or hampering long-term collaboration in technologically lagging economies (Barbosa et al., 2024). In this case, we adopt a similar dynamic approach, as our objective is to investigate the formation and evolution of a peripheral co-patent network, highly dependent on foreign interests, and how it responded to a profound institutional shock—the Cuban Revolution of 1959—which triggered a structural change of the island's social and economic ecosystem. In particular, we pose the following research questions and formulate hypotheses regarding their likely answers:

- First, *what were the topological properties of the emerging Cuban patent network under strong U.S. influence and a colonial capitalist logic before 1959?* The patent statistics presented in the descriptive section lead us to hypothesize that U.S. patentees—especially in the chemical/pharmaceutical sector—held a central role in the network during the pre-revolutionary period, contributing to increasing its size and complexity and generating large U.S.-dominated components.
- Second, *to what extent did the revolution and the institutional shock cause a measurable impact on the patent network topology?* Fig. 1 and Table 2 suggest that the impact was high, given the fall in the number of patent records, especially among U.S. and Cuban innovators. Thus, we expect a fall in the size and connectivity of the network and a progressively central role of non-U.S. European patentees, still focused on chemical/pharmaceutical research.
- Third, *how did the patent network evolve during the subsequent post-revolutionary years of Cuba's gradual transition to socialism?* The geopolitical conflict with the United States, the progressive changes in the island's international ties, and the growing participation of the state and public institutions in the design of scientific and technological activities suggest—as does the descriptive section—a progressive attrition of the patent network size and connectivity and an increasingly irrelevant topological role of U.S. pharmaceutical companies in favor of a more central position of Cuban institutions and non-U.S. firms. This would imply a sectoral diversification from chemical research to other key activities in a context of import substitution and rising nationalism.
- Fourth, and finally, *what was the rate of international collaboration in the patent network before and after the revolution?* As homophily—the principle that contact between similar people occurs at a higher rate than among dissimilar people—is ubiquitous in social networks (Au, 2023; Leszczensky and Pink, 2015; McPherson et al., 2001), we anticipate a low rate of international collaboration in general. However, we hypothesize that it would be more probable in the relatively open pre-revolutionary context than after the revolution, especially between U.S. and Cuban innovators. Likewise, we do not anticipate significant patent collaboration between Cuba and non-U.S. countries in the new geopolitical context, given, first, the complex international relationships of the island and, second, the development of other forms of scientific cooperation with the communist bloc that might not leave a trace in the patent system.

3.2. SNA Methods

In this study, we construct a co-patent network which represents a one-mode projection of the underlying bipartite structure linking innovators to patents. In the network two innovators (nodes)—whether patentees or inventors—are linked if they have a patent in common (edges). For instance, if inventor A works with inventor B on a patent in 1952, and subsequently, inventor A is related to patentee C on another patent in 1953, all three become interconnected. Thus, we consider 'collaboration' in a broader and comprehensive sense, including partnerships or employment relationships, insofar as all of them imply to some extent circulation of knowledge. Although the literature typically examines patentee and inventor networks separately, the

Table 2
Top ten innovators by number of Cuban patents they were involved in, by sectors of main patenting activity, and by time windows (1947-1976).

1947-1952

Main Actors	Residence	Patents involved	Main Sectors of Patenting Activities*
General Electric Company	US	45	Electricity & Others
American Cyanamid Company	US	42	Pharmaceutical & Other Chemicals
Colgate Palmolive Peet Company	US	36	Other Chemicals & Pharmaceutical
The Sherwin Williams Company	US	33	Other Chemicals
Wingfoot Corporation	US	26	Other Chemicals, Services & Others
Sharp & Dohme, Incorporated	US	25	Pharmaceutical
United States Rubber Company	US	17	Other Chemicals & Agriculture
Parke Davis & Company	US	16	Pharmaceutical
Sterling Drug Inc.	US	15	Pharmaceutical
Ciba A. G.	CH	15	Pharmaceutical

1953-1958

Main Actors	Residence	Patents involved	Main Sectors of Patenting Activities*
Merck & Co, Inc.	US	88	Pharmaceutical
Chas Pfizer & Co, Inc.	US	74	Pharmaceutical
Hoffmann - La Roche & Co. A. G.	CH	61	Pharmaceutical
The Sherwin Williams Company	US	57	Other Chemicals
Société des Usines Chimiques du Rhône Poulenc	FR	53	Pharmaceutical
The Goodyear Tire & Rubber Company	US	50	Transport & Other Chemicals
E. I. Du Pont de Nemours & Company	US	48	Textile & Other Chemicals
Perfogit Societa Per Azioni (SpA)	IT	38	Pharmaceutical & Other Chemicals
United States Rubber Company	US	37	Transport & Other Chemicals
American Cyanamid Company	US	36	Pharmaceutical

1959-1964

Main Actors	Residence	Patents involved	Main Sectors of Patenting Activities*
Sandoz A. G.	CH	91	Other Chemicals & Pharmaceutical
Merck & Co, Inc.	US	75	Pharmaceutical
Hoffmann - La Roche & Co. A. G.	CH	60	Pharmaceutical & Other Chemicals
American Cyanamid Company	US	54	Pharmaceutical
Miles Laboratories, Inc.	US	46	Other Chemicals & Pharmaceutical
Jucker, Ernest	CH	34	Other Chemicals & Pharmaceutical
Hoffmann, Albert	CH	32	Pharmaceutical & Other Chemicals
Sandoz Patents Limited	CA	31	Other Chemicals & Pharmaceutical
Montecatini (S. G. per l'Indus. Min. e Chim.)	IT	31	Other Chemicals & Pharmaceutical
Société des Usines Chim. du Rhône Poulenc	FR	30	Pharmaceutical & Other Chemicals

(*continued on next page*)

Table 2 (*continued*)

1965-1970

Main Actors	Residence	Patents involved	Main Sectors of Patenting Activities*
Hoffmann - La Roche & Co. A. G.	CH	47	Pharmaceutical & Other Chemicals
Farbwerke Hoechst A.G. vor M. L. & Brüning	DEU	32	Pharmaceutical & Other Chemicals
Muth, Karl	DEU	23	Pharmaceutical & Other Chemicals
Weber, Helmut	DEU	23	Pharmaceutical & Other Chemicals
Weyer, Rudi	DEU	23	Pharmaceutical & Other Chemicals
Aumüller, Walter	DEU	22	Pharmaceutical & Other Chemicals
Sternbach, Leo Henryk	US	18	Pharmaceutical & Other Chemicals
Estado Cubano	CU	16	Mining and coal
Farbenfabriken Bayer, A. G.	DEU	14	Agriculture
Sandoz Patents Limited	CA	13	Other Chemicals & Pharmaceutical

1971-1976

Main Actors	Residence	Patents involved	Main Sectors of Patenting Activities*
Centro Nacional de Investigaciones Científicas	CU	34	Pharmaceutical, Other Chemicals & Other Sectors
Imperial Chemical Industries, Limited (ICI)	GB	15	Agriculture, Other Chemicals & Pharmaceutical
Massey Ferguson Services N. V.	SX	15	Sugar & Machinery
Instituto Nacional de Reforma Agraria	CU	14	Agriculture, Sugar & Tobacco
Universidad de la Habana	CU	14	Pharmaceutical, Other Chemicals & Sugar
Universidad Central de las Villas	CU	10	Sugar & Machinery
Le Nickel, Societé Anonyme	FR	10	Other Chemicals & Mining
Ministerio de Minería y Geología	CU	10	Mining, Other Chemicals & Metals
Universidad de Oriente	CU	9	Sugar
Sherritt Gordon Mines Limited	CA	9	Other Chemicals, Mining & Machinery

Source: Sáiz et al. (2022).
* For the sectoral analysis of patents, see Section 4.4, where Table 4 lists all the industries. In the *Chemical* sector, we differentiate *Pharmaceuticals* from *Other Chemicals*.

disambiguation process applied to the Cuban patent database allows integrating both groups into a single network, thereby providing, for the first time, a more comprehensive understanding of their roles within the innovation system. For instance, see in Figs. 2 and 3 the possibility of identifying firms, inventors, and institutions within the innovation clusters, or in Section 4 the characteristics of international connections among these actors. To carry out the analysis, the first step involves constructing an innovator-patent interaction dataset from 1947 to 1976 (9,842 patents and 9,530 innovators), where each patent appears as many times as the number of its patentees/inventors (resulting in 16,503 rows). Then, we construct five co-patent networks, one for each of the time windows that we consider to study the evolution of the system. For each period, we compute a series of topological measures commonly used to analyze social networks (e.g., average degree, betweenness centrality, diameter, etc.). The analysis allows us to study the transformation of the innovation system, which, combined with the study of sectoral and geographic differences, sheds light on the reaction of a developing IPR network to a systemic—institutional—shock. Before discussing the periodization of the network and the topological measures, we make three methodological remarks:

First, the proposed network analysis focuses on the characteristics of the subset of new patents registered in each time window instead of considering the cumulated stock of patents at any given moment. This approach, consistent with the literature (e.g., Bianchi et al., 2020), aims to identify and analyze the changes that take place in each period, focusing on the network dynamics and differential changes. Second, as we incorporate both patentees and inventors into the patent network, this may result in the formation of large components (often 'stars') that represent companies or institutions with extensive patent portfolios and diverse inventor bases. While such structures can illuminate internal collaboration dynamics—i.e., entrepreneurial hidden networks (see Barbosa et al., 2024)—they do not necessarily indicate broader collaborative activity. Nevertheless, after accounting for these structural effects, we have opted to construct the network in such a manner, in alignment with the objective of exploring multiple dimensions of the Cuban innovation system, following the approach established in the aforementioned literature on NISs (Edquist, 2005; Freeman, 1995, 1987; Lundvall, 1992; Nelson, 1993). Third, as stated in the descriptive section and also based on the NIS methodological framework, our study considers all patents registered on the island, encompassing both national and international innovators. Since the country's economic history has been rooted in external influences over the years, this perspective is essential for a comprehensive understanding of the Cuban innovation system, its openness, and its geopolitical dynamics (e.g., degree of homophily, as we discuss in Section 4 below). Following independence from Spain, the island came under significant U.S. influence, which fostered industrialization and economic growth, albeit at the cost of deepening Cuba's foreign subordination. The post-revolutionary shift, in turn, restructured these dependencies, linking Cuba to a different geopolitical and economic sphere: the soviet bloc, with its own set of constraints and opportunities.

3.3. Network measures

We study well-known network topology measures concerning its structure and connectivity, which allows us to characterize the general evolution of the Cuban NIS. Considering the patent network represented by the Graph $G=(V, E)$, where $V=\{1,...,v,...,N\}$ is the set of nodes (Vertices) and $E=\{1,...,e,...,M\}$ is the set of links (Edges), we compute and analyze, for each period:

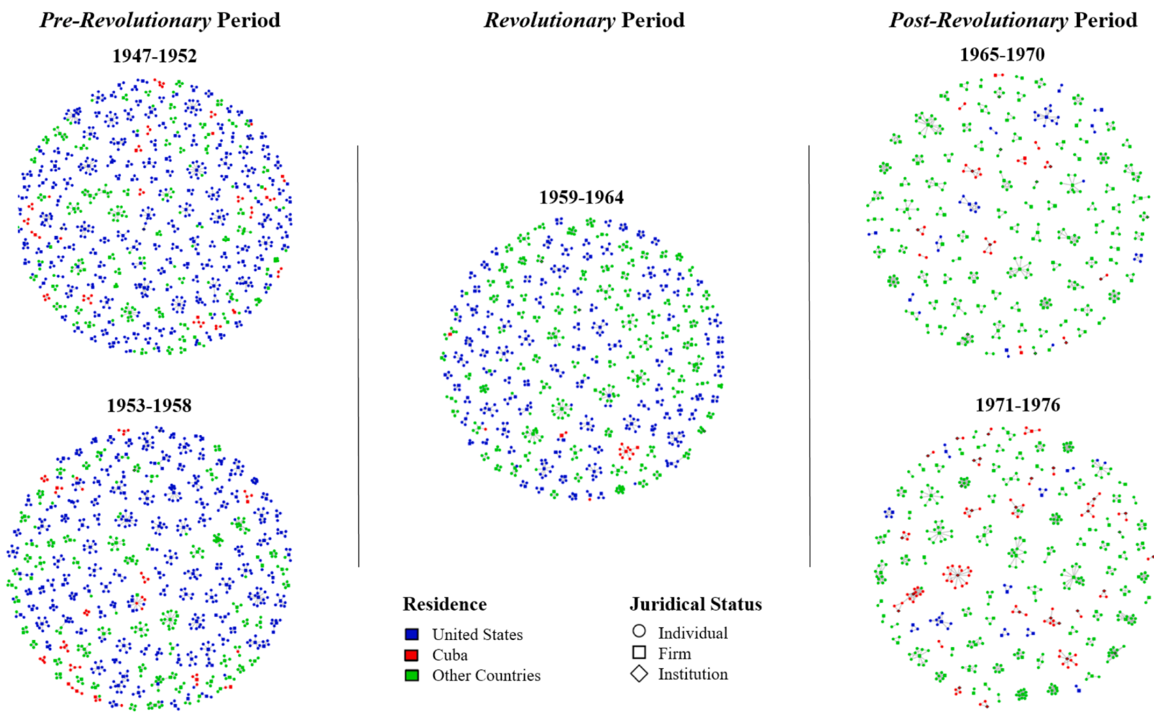

Fig. 2. Small & medium components in Cuban co-patent networks (1947-1976).
Note: For ease of representation, only components with more than 3 nodes are displayed in the first and third time windows, and only components with more than 4 nodes in the second time window, given the higher fragmentation observed in those periods. All components (i.e., groups comprising at least 2 nodes) are shown in the remaining windows. Source: Computed from the network dataset.

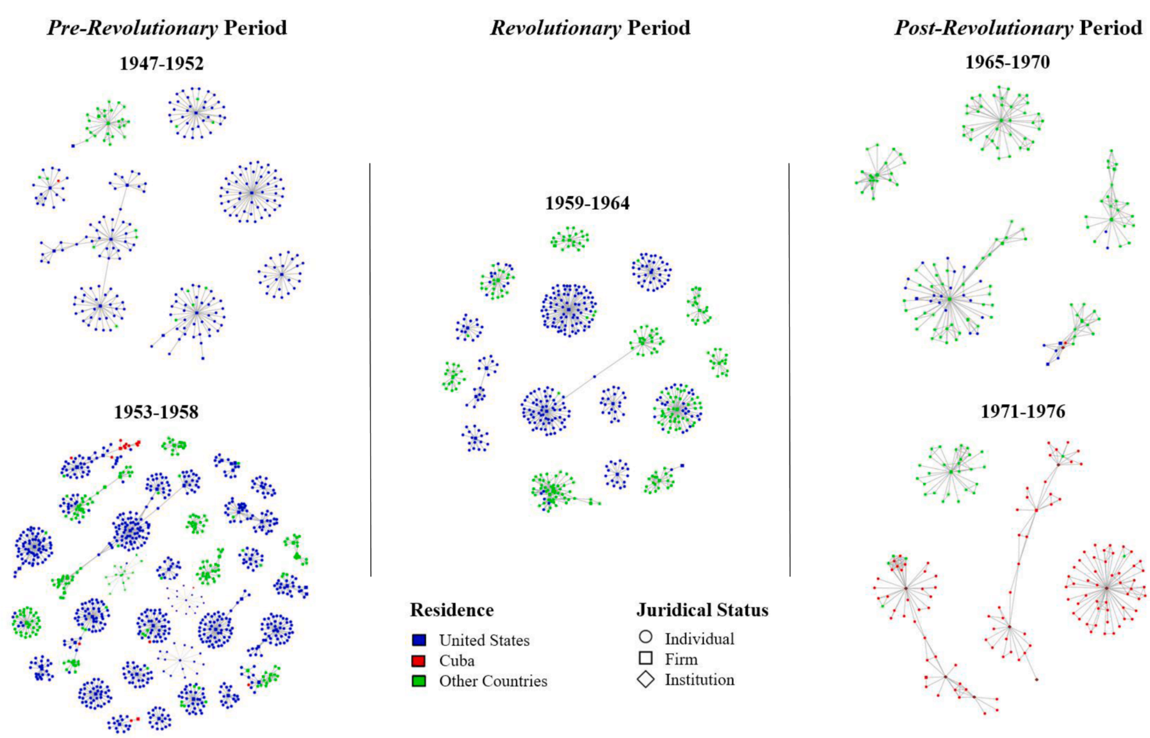

Fig. 3. Large components in Cuban co-patent networks (1947-1976).
Note: For ease of representation, only components with at least 15 nodes are shown. Source: Computed from the network dataset.

- *Size and connectivity: 'Total Number of Nodes (#N)'* and *'Percentage of Isolated Nodes (%IsolNodes)'*. These measures help assess the maximum potential for interactions in the network, as well as the basic degree of knowledge dissemination across the system (Stuck et al., 2016). This way we observe how the Cuban patent network has evolved in terms of size and connectivity through the social, economic, and political regime changes.
- *Clustering and community formation*: *'Total Number of Components (#Comp)'* (clusters of innovators with at least two nodes) and *'Size of the Largest Component (SizeComp)'* in each period. Technological changes and disruptions, although they may originate from small groups—or even individuals (Wu et al., 2019)—usually coalesce into larger components that facilitate the development and funding of novel technologies. In general, the presence of large components and numerous groups is an indicator of development in innovation networks (Fleming et al., 2007).
- *Collaboration patterns*: To examine the structure and evolution of collaborative dynamics within the Cuban innovation system, we compute key network metrics at both the node level (using averaged indicators) and the overall network level (using direct indicators). These metrics allow capturing not only the intensity and distribution of connections but also the system's internal cohesion, hierarchical structure, and potential for knowledge diffusion (Newman, 2018). Specifically, we calculate:

- *'Average Degree'* ($\overline{E}$), which reflects the mean number of direct links per actor/node v and offers a basic measure of individual participation in the network:

$$\overline{E} = \frac{1}{N}\sum_{N} deg(v), \tag{1}$$

where N is the total number of nodes, and $deg(v)$ is the degree of node v.

- *'Average Betweenness Centrality'* ($\overline{B}$), to capture the extent to which actors serve as intermediaries in the flow of information—thus identifying key brokers or gatekeepers in the system:

$$\overline{B} = \frac{1}{N}\sum_{N} b(v), \tag{2}$$

where $b(v)$ is the betweenness centrality of node v; and, finally,

- *'Average Density'* (*AD*), to quantify how densely connected the network is, calculated as the ratio of existing edges to the maximum number of possible links in the network, providing insight into local cohesion:

$$AD = \frac{2M}{N(N-1)}, \tag{3}$$

where M is the total number of links in the network.

Then we evaluate the following two indicators that inform us about the system's compactness and the efficiency of knowledge transmission across the network; i.e.,

- *'Average Path Length'* ($\overline{L}$), which measures the average number of steps along the shortest paths for all possible pairs of nodes in the network:

$$\overline{L} = \frac{1}{N(N-1)}\sum_{v\neq u} d(v,u), \tag{4}$$

where $d(v,u)$ is the bilateral shortest path distance between nodes v and u, $v\neq u$; and

- *'Diameter'* (*Dm*), which is the maximum distance among all shortest paths $d(v,u)$ found in the network:

$$Dm = \max\{d(v,u) | v \neq u,\ v,u \in V\}. \tag{5}$$

Moreover, to study the tendency of actors to form tightly knit groups or communities—often reflecting shared institutional or sectoral affiliations—we compute the following clustering indicators:

- *'Average Clustering Coefficient'* ($\overline{C}$), which measures how close a node's neighbors are to being a complete group (i.e., how interconnected a node's neighbors are):

$$\overline{C} = \frac{1}{N}\sum_{N} C(v), \tag{6}$$

where $C(v)$ is the local clustering coefficient of node v, defined as $C(v) = \frac{2k_v}{\deg(v)(\deg(v)-1)}$, where k_v is the observed number of links between the neighbors of node v.

- *'Global Clustering Coefficient'* (C_g), which captures the overall tendency of the network to form closed triplets (triangles). It measures how likely it is that two nodes, both connected to a common third node, are also connected to each other, thus providing a general indication of network transitivity:

$$C_g = \frac{\sum_v \text{ClosedTriplets}_v}{\sum_v \text{Triplets}_v}. \tag{7}$$

Finally, we compute two additional network measures:

- *'Centralization' (Cn)*, which helps assess the extent to which the network is organized around a few highly connected nodes, revealing patterns of dominance or decentralization in collaboration:

$$Cn = \frac{\sum_{v\in V}(\max(deg(v)) - deg(v))}{(N-1)(N-2)}, \tag{8}$$

where $\max(deg(v))$ is the maximum degree for a node found in the network; and

- *'Average Neighborhood' ($\overline{N}$), which* measures the average number of nodes that are directly connected to each node's neighbors, offering additional information about the local structure and potential for indirect interaction:

$$\overline{N} = \frac{1}{N}\sum_{v\in V}\frac{\sum_{u\in\Gamma(v)} deg(u)}{deg(v)}, \tag{9}$$

where $\Gamma(v)$ is the set of neighbors of node v.

All the above measures allow us to explore the network's evolution and assess the impact of the revolutionary movement on the Cuban NIS. Additionally, a comprehensive understanding of the innovation landscape also requires examining both sectoral and geographical dimensions, given Cuba's contemporary recognition in healthcare and biotechnology among developing countries (Guzmán-Sánchez et al., 2018; Perez Villanueva and Albizu-Campos Espiñeira, 2023) and given its unique geopolitical context. Specifically, we analyze the sectoral distribution of patents to understand how innovation evolved across technological domains, and the innovators' country of residence to explore differences between national and international interactions. The next section presents the main results, organized chronologically, to provide a detailed account of these findings, answer the research questions, and test our hypotheses.

4. Cuban patent networks pre- and post-1959 revolution: The reorientation of an emerging innovation system

4.1. The Cuban Pre-Revolutionary patent networks (1947-1958)

Cuba's economic structure was traditionally based on a few key sectors, particularly sugar and tobacco. During the first third of the twentieth century, external trade—primarily with the United States and with sugar as its main export—reached outstanding growth rates. In fact, the island experienced sustained economic growth until 1925, largely driven by the expansion of the U.S. sugar market, where Cuba satisfied half of the demand (Dye and Sicotte, 2004). However, this

Table 3
Network topological measures, Cuba (1947-1976).

		Pre-Revolutionary Period		*Revolutionary* Period	*Post-Revolutionary* Period		Aggregate change (%)
Indicator	**Notation**	**1947-1952**	**1953-1958**	**1959-1964**	**1965-1970**	**1971-1976**	**1947-1976**
Total Number of Nodes	*#N*	3,052	4,500	2,013	625	684	-77.60
Connected Nodes	*#ConnNodes*	1,949	3,400	1,696	588	664	-65.90
Isolated Nodes	*#IsolNodes*	1,103	1,100	317	37	20	-98.19
Percentage of Isolated Nodes	*%IsolNodes*	36.14%	24.44%	15.75%	5.92%	2.92%	-91.89
Size of the Largest Component	*SizeComp*	74	132	89	58	51	-31.08
Total Number of Components	*#Comp*	564	807	330	115	111	-80.32
Average Degree	$\overline{E}$	1.973	2.422	2.922	3.497	3.786	91.87
Average Betweenness	$\overline{B}$	7.270	16.057	13.597	7.776	6.635	-8.65
Average Density	*AD*	0.0010	0.0007	0.0017	0.0060	0.0067	562.80
Average Path Length	$\overline{L}$	2.909	3.833	2.937	2.618	2.458	-15.50
Diameter	*Dm*	11	19	15	14	9	-18.18
Average Clustering Coefficient	$\overline{C}$	0.867	0.862	0.901	0.925	0.927	6.89
Global Clustering Coefficient	C_g	0.277	0.285	0.278	0.514	0.620	123.97
Centralization	*Cn*	0.025	0.019	0.050	0.079	0.080	222.95
Average Neighborhood	$\overline{N}$	10.460	18.469	20.792	14.156	15.160	44.93

Source: Computed from the network dataset.
Note: Averaged indicators (e.g., $\overline{L}$*)* are computed at the node level.

mono-productive, export-oriented development model made the economy vulnerable to fluctuations in the global market, such as during the international recession of the 1930s. As the twentieth century progressed, U.S. influence deepened, sustaining economic growth in the 1940s and 1950s, although alongside rising inequality—particularly among those without ties to U.S. commercial interests (CIEM, 1984; Morley, 1987). The coalition that brought Batista to power, consisting of military figures and affluent landowners from the sugar industry, further widened the wealth gap, while Cuba received substantial military, financial, and logistical support from the United States (Smith and Walter, 2016).

The innovation system was not an exception to this influx of resources. During the *Pre-Revolutionary* period, as previously shown in Fig. 1, the share of patent registrations involving U.S. residents grew steadily, reflecting the dominance of this country in Cuba's IPR system during Batista's regime, reaching 50% in 1955. Likewise, after constructing the patent networks and obtaining their topological structures for all the periods studied (Table 3), the results support our first research hypothesis (Section 3.1), confirming the upward trend during the *Pre-Revolutionary* phase, characterized by increases in network size and connectivity—under strong U.S. influence—up to 1959.

The third and fourth columns of Table 3 corresponding to the *Pre-Revolutionary* period reveal an expansion of the network size, characterized by the increase of '*Total Number of Nodes*' by 47%, a significant decrease in the '*Percentage of Isolated Nodes*' (from 36.14% to 24.44%, with the absolute number of isolated nodes barely changing), an increase in the '*Size of the Largest Component*' (from 74 to 132), and, overall, positive changes in network statistics such as '*Average Degree*' and '*Diameter*'. However, this evolution was not comprehensive, as certain network measures experienced a slight decrease. Specifically, statistics such as '*Average Density*' and '*Centralization*' reduced in the second sub-period, suggesting that the network did not experience a general increase in interconnection. More relevant, while strategically advantageous for the United States, this development in the network did not imply increased collaboration with local inventors, as demonstrated in Section 4.5 below—devoted to the geography of collaboration—and in line with our fourth hypothesis regarding homophily (see Section 3.1). Thus, although U.S. influence fostered the innovation environment, it resulted in unequal power dynamics that subordinated Cuban interests to those of the United States, as widely emphasized by scholars advocating dependency theory (e.g., Santos, 1970, among others). This research field highlights how peripheral economies may become structurally constrained by their integration into global value and knowledge chains, thereby limiting their capacity to protect and capitalize on their intellectual creations and innovations.

Figs. 2 and 3 depict this scenario, where, as expected, the central nodes of the network (those more connected) were major U.S. corporations registering patents in Cuba.[14] Many of these firms had direct commercial and industrial interests on the island, with most primarily oriented towards the chemical/pharmaceutical industry, such as *American Cyanamid Company* or *Colgate Palmolive Peet Company*. They registered numerous tetracyclines, antibiotics, and, in general, drugs used to treat tropical and infectious diseases. Other central nodes—like *The Sherwin-Williams Company*—were related to generic chemical products (insecticides, herbicides, coatings), while only *General Electric* branched into other sectors such as electricity. However, from 1953, there was also an increase in other key players, i.e., highly connected actors, that partially qualifies our initial hypothesis on U.S. dominance. For instance, we find small/medium Cuban clusters centered around firms such as *Compañía Rayonera Cubana* or *Plásticos Industriales Extrusos, S.A.*, and several large components with key European firms, such as *Hoffmann-LaRoche & Co. A. G.* from Switzerland and *Farbenfabriken Bayer, A. G.* from Germany. Although isolated actors are not represented in these graphs, it is worth mentioning that Cuban patentees predominated among them—usually technicians, professionals, or businessmen who registered incremental innovations related to their own activities.

4.2. *The Cuban Revolution and its patent network (1959-1964)*

During the late 1950s, the peak of internal inequalities, social discontent, and economic vulnerabilities precipitated a political collapse, prompting the 1959 revolutionary transformation. Fidel Castro led a movement that sought to address the root causes of Cuba's challenges and assert the nation's autonomy from external influences, marking a significant and controversial turning point in Cuban and American history. This *Revolutionary* period comprises the early years of Castro's rule, during which the government focused on addressing the aforementioned critical economic challenges, triggering key structural changes. These included agricultural reform—confiscating large estates owned mainly by U.S. citizens—as well as measures to address balance of payments problems, external liquidity constraints, and the supply of

[14] We remind the reader that in the descriptive section we listed the top U.S. innovators by number of patents. Here, we identify the most connected nodes in the network, which may coincide with those holding more patents or not. Although there is usually a correlation, they are separate issues.

oil (CIEM, 1984; Garcia Molina, 2005; Sánchez, 1994). These changes sought to alleviate immediate concerns, rooted in land redistribution, nationalization of key industries, and healthcare and education, but they did not result in a substantial overhaul of the Cuban economy (Brundenius and Torres Pérez, 2014).

Gradually, divergences between the revolutionary government and the United States led to a series of confrontations, culminating in Cuba's establishment of diplomatic relations with the Soviet Union in 1960 and the adoption of several policies opposed to U.S. interests, including the nationalization of *Standard Oil* and *Shell* refineries, as well as 36 U.S. sugar mills that were operating on the island for over decades (Recarte, 1980, p. 46). The shift in political orientation, focused on improving social welfare through socialist ideals, influenced the innovative environment. The aim to eliminate large landowners in the countryside and private property, within a shift toward not-for-profit uses of the means of production, changed the scope and the incentives for innovators, resulting in a steady attrition of related activities.

Indeed, the Cuban patent network experienced the beginning of a structural change, as the middle column of Table 3 shows. The shift in the network's trajectory after Castro's arrival prompted a dramatic decrease in its size, with a reduction of 55% in *'Total Number of Nodes'* between 1953-1958 and 1959-1964. The network contracted because of the departure of numerous middle- and upper-class Cubans from the island, the measures taken by Castro against U.S. companies, and the prohibition by the U.S. government on maintaining economic relations with Cuba.[15] The increases found in *'Average Degree'* and *'Average Density'*, along with the contraction of *'Diameter'* and *'Average Path Length'*, show that the network evolved into a smaller but more connected one, where nodes that were isolated or sought entry did not survive the revolution (hence the general decline in '*Isolated Nodes*' from 24.44% to 15.75%). In the central network graph of Figs. 2 and 3, illustrating the *Revolutionary* period (1959-1964), we can see a more disconnected central area than in the previous periods, with a smaller number of large clusters. This partially confirms our second hypothesis outlined in Section 3.1, regarding the size of the network, although the high disappearance rate of isolated nodes has an unexpected effect of increasing connectivity at this smaller scale.

Therefore, many innovators abandoned the patent system due to the structural changes prompted by the revolutionary government, particularly the collectivization and nationalization measures implemented in the first triennial plan (1961-1963) (Garcia Molina, 2005; Rosenthal, 1996). The exodus of professionals and the lack of market incentives inevitably affected local and foreign investments in innovative activities (IPRs included). However, while several U.S. companies exited the island (or stopped patenting from abroad), others, such as *American Cyanamid Company, Merck & Co., Inc.*, and *Miles Laboratories, Inc.*, remained among the top patenting actors. The topological network analysis shows that the previous accumulation of human and monetary capital generated on the island by the United States, coupled with the fact that institutional changes have lagged effects and are not instantaneous (unlike the effects of natural catastrophes or calamities on networks), enabled incumbent U.S. firms to relatively sustain its activities, at least in the first years after the revolution. Nevertheless, we also observe a substitution effect whereby firms from a variety of other countries consistently rank in the top positions, becoming central actors of the patent network (Swiss companies such as *Hoffmann-La Roche & Co. A. G.*, Italians such as *Montecatini*, and Dutch such as *Shell Internationale Research Maatschappij, N.V.)*.[16] Again, this partially corroborates our second hypothesis, although it should be nuanced by the interesting resilience of U.S. firms, still among the main large components of the network (see Fig. 3).

Despite the advances of the new government in addressing the most pressing socio-economic concerns, a major geopolitical confrontation in October 1962 changed the course of Cuba's development. Castro's alignment with the Soviet Union prompted the United States to enforce an embargo—officially instituted on February 7, 1962, through the *Foreign Assistance Act* of 1961—that significantly exacerbated the country's existing economic woes (Brundenius and Torres Pérez, 2014). This further limited international relations and imposed additional financial constraints, hampering the establishment of robust innovation hubs and deepening structural transformations across the economy, politics, society, and the innovation system (Arencibia-Jorge and De Moya-Anegón, 2010; Kwon et al., 2019).

4.3. *The Cuban post-revolutionary patent networks (1965-1976)*

After 1964, when the first triennial plan ended, Cuba intensified its efforts to complete the agrarian reform by dismantling the grip of large sugar estates and external economic dominance, fostering a more assertive approach to economic restructuring (Eckstein, 1994). Meanwhile, the U.S. embargo hindered Cuba's access to international markets and financial resources, further deepening its reliance on the Soviet Union and other socialist countries for economic, trade, and military support. This relationship started around 1964 and endured for decades, having a profound impact on the trajectory of the island, including the adoption of socialist policies and alignment with the communist bloc, culminating in its adhesion to the Council for Mutual Economic Assistance (COMECON) in 1972 (Morley, 1987; Smith and Walter, 2016; Tsokhas, 1980).

In this context, the innovation system experienced significant changes, aligning related legislation with socialist principles. IPRs refocused to emphasize the use of scientific and technological advancements for the benefit of the entire society, discouraging the protection of ideas with commercial objectives (Brundenius and Torres Pérez, 2014; Martínez-Montenegro, 2018). Indeed, in one of his speeches, Castro commented on his disregard for IPRs, asserting that creations of the mind belong to the entirety of humanity and hence should not be subject to individual ownership.[17] IPR reforms can yield heterogeneous outcomes depending on contextual factors and the nature of structural changes (Bondarev, 2018). However, recent empirical studies focusing on Latin American and Caribbean countries suggest that strengthening IPRs tends to have positive effects, particularly encouraging foreign investments (Viglioni et al., 2023). At this stage, Cuba was the opposite case, as the governmental disincentives towards private innovation, along with the conflict with the United States, prompted an exodus of inventors and businesses. Not only did several major national firms and brands abandon the island,[18] but so did numerous U.S. companies, which were expropriated, exited Cuba, or, simply, ceased patenting from abroad. These strategic moves caused a notable drain of knowledge and expertise, creating an unfavorable environment for IPRs on the island and contributing to the erosion of the country's innovation

[15] There were a first wave of migration between 1959 and 1962 and a second wave from 1965 to 1974 (see Pedraza, 1998). Almost 600,000 Cubans left the island between 1959 and 1972, according to the "*Anuario Estadístico de Cuba"* of 1974 (about 7.5% of the total population). Furthermore, as reported by Perez-Riverol (2020), this process has continued, and the migration of Cuban scientists and technicians to other countries has had a significant impact in Cuban research output between 1990 and 2020.

[16] The shift in political ideology during the revolution led to residents in socialist areas, like the German Democratic Republic, to begin patenting inventions in Cuba, mirroring what occurred in the Federal Republic of Germany. In 1964, there were 9 patents registered on the island from each of both countries.

[17] "Discurso por víctimas de bombardeo", *Granma*, April 19, 1967

[18] To exemplify this issue there is one well-known case: the brand *Havana Club* experienced expropriation (Carlson et al., 2001) and the owning firm *Bacardi* opted to relocate to Puerto Rico (Gjelten, 2009). The legal battle for the trademark has been ongoing for decades.

landscape during this period—a decline that growing proximity to the Soviet orbit, collaboration with other Western countries, or the state's efforts to reorganize science and technology would attempt to reverse.

The topological analysis confirms the severe attrition of the patent network after 1965. Deepening the trend of the *Revolutionary* period, the network became even smaller albeit more connected due to the disappearance of individual (isolated) nodes. The total size of the network reduced once again by 69% between 1959-1964 and 1965-1970, maintaining only a few isolated nodes and reaching a peak of 97% connectivity from 1971 to 1976 (see Table 3). While most isolated innovators vanished, a few institutional hubs emerged (concentrating on basic research and technological activity), as well as several new foreign innovators (see Table 2, Fig. 2, and Fig. 3). Therefore, the mentioned contraction of the network, the disappearance of isolates, and the emergence of public research hubs explain why measures like *'Average Degree'*, *'Average Density'*, or *'Average Local Clustering'* show an increase in agent interconnection, while there is a simultaneous splitting of network members and connection pathways, as evidenced by the reduction in '*Average Betweenness'*, *'Average Path Length'*, and *'Diameter'*, especially in the last time window. This validates most of our third hypothesis outlined in Section 3.1, except for the unanticipated effect of the reduction in network size on connectivity. The network transformed into a smaller set of components led by Cuban public institutions and a few European firms, with almost no isolated nodes, which strengthened overall network cohesion.

Considering the geographical aspect of the analysis, we observe again that—despite the issues with the new government and the supposed ban on relations with the island—the U.S. presence did not disappear. In the *Post-Revolutionary* period, there were just 105 U.S. patentees/inventors involved in Cuban patents (compared to 3,120 in the *Pre-Revolutionary* period). Among them, aforementioned chemical firms, such as *American Cyanamid Company*, registered a few patents, while other companies, such as *Chemical Construction Corporation* and *AMAX Inc.*, managed to register their inventions on the island, continuously overcoming international bans. Yet, in this period U.S. firms were neither among the top patent applicants on the island nor among the nodes with the highest degree, i.e., they did not form part of the largest and most connected components, occupying peripheral positions in the network, which fully corroborates our third hypothesis. Meanwhile, the substitution process by innovators from other countries intensified, including those from Switzerland (79) or Germany (233, several from East Germany).[19] Other countries closer to the soviet bloc arose in the network, such as Czechoslovakia (26), Poland (24), and the USSR itself (37). Among these foreign applicants, we find big pharmaceutical firms such as *Hoffmann-LaRoche & Co. A. G.* or *Farbenfabriken Bayer, A. G.* However, during the last time window (1971-1976), Cuban public institutions, research centers, and universities also emerged as main hubs, signaling that the revolutionary government's efforts to promote education and innovation on the island yielded tangible results. This entirely aligns with what we hypothesized in Section 3.1.

4.4. Sectors driving patent evolution

In addition to the SNA analysis, the sectoral study of patents in Table 4 confirms the dominance of the chemical sector during the *Pre-Revolutionary* period (1947–1958). Driven by pharmaceuticals, '*Chemicals'* accounted for a third of registered patents between 1953 and 1958, validating our first hypothesis once again (see the main U.S. companies operating in this sector in Table 2). Thus, the protection of technological innovation in Cuba did not primarily focus on traditional activities like '*Tobacco'* or '*Sugar'*, as might be expected, but rather on other kinds of

Table 4
Sectoral distribution of patents by time window, Cuba (1947-1976).

	Pre-Revolutionary Period		*Revolutionary* Period	*Post-Revolutionary* Period	
SECTOR	1947-1952	1953-1958	1959-1964	1965-1970	1971-1976
Services	19.76%	12.78%	7.18%	3.27%	2.74%
Chemical	18.58%	28.57%	47.06%	45.84%	30.68%
—Pharmaceuticals	10.32%	19.75%	29.39%	26.45%	14.25%
—Other Chemicals	8.27%	8.83%	17.67%	19.40%	16.44%
Construction	9.01%	8.31%	4.89%	6.30%	3.56%
Textile	8.53%	6.51%	4.30%	1.76%	0.82%
Sugar	6.62%	3.61%	2.41%	3.78%	16.99%
—Industrial Transformation	5.95%	3.38%	2.18%	2.27%	10.14%
—Cultivation & Harvesting	0.67%	0.23%	0.24%	1.51%	6.85%
Machinery and Equipment	6.18%	6.81%	4.59%	3.02%	8.77%
Agriculture and Cattle Farming	5.07%	4.54%	6.48%	11.59%	14.52%
Paper and Graphic Arts	4.97%	6.20%	3.42%	0.50%	0.82%
Electricity	3.66%	2.81%	2.65%	5.79%	4.38%
Mining and Coal	1.38%	1.95%	2.94%	7.56%	5.48%
Other Sectors	16.23%	17.91%	14.08%	10.58%	11.23%
TOTAL	2,976	4,406	1,698	397	365

Source: Sáiz et al. (2022)
Notes:
(1) Sectors are sorted in decreasing order according to their share in the first time window.
(2) Only sectors with at least 5% of patents in any given period are shown.
(3) Other sectors include: Aeronautics, Arms Industry, Basic metals, Beverages, Communications, Food, Gas and lighting, Lumber industry, Non-rail transportation, Railway, Sea transport, canals and ports, and Tobacco.

advancements. On average, 15% of all patents registered during this period were related to medicines, drugs, cosmetics, and similar products, only slightly surpassed by the heterogeneous *'Services'* category (16%), which includes goods related to domestic infrastructure, household items, leisure and culture, and health and personal care, among others. As stated in the descriptive section, it was in these types of low-tech activities that more Cuban patentees were involved.

Therefore, the results suggest that the pharmaceutical sector played a crucial role in the country's patent system, although further complementary evidence would be necessary to assess its impact on knowledge diffusion and domestic innovation capabilities, particularly because foreign firms had strong incentives to protect these kinds of products in the Cuban market. Before 1959, Cuba's relatively prosperous economy and strategic location in the Caribbean rendered the island attractive to U.S. pharmaceutical companies seeking to expand their operations, as well as a few European firms (mainly from Switzerland and France).[20] The high prevalence of tropical diseases on the island (such as malaria), coupled with an inadequate public healthcare system, prompted a favorable reception to foreign investments—especially from the U.S.—which explains the establishment of numerous companies and scientists during Batista's dictatorship. This gradual influx contributed to the accumulation of human capital in the healthcare sector and, to a certain extent, to knowledge spillovers to local actors aimed at improving the population's living conditions. A representative example during the *Pre-Revolutionary* period is a group of local physicians who, having managed a domestic pharmaceutical laboratory since 1927, went on to establish and develop the *Instituto Biológico Cubano*, a key Cuban scientific institution capable of competing with foreign laboratories before 1959 (Ravenet Ramírez, 2024).

[19] From the 233 German innovators in the Cuban network after the revolution, 65 were from the socialist German Democratic Republic, especially active during the period 1965-1970.

[20] Such as *Ciba A. G.; Hoffmann - La Roche & Co. A. G.*; or *Société des Usines Chimiques du Rhône Poulenc*.

During the *Revolutionary* period (1959-1964), along with the beginning of a geographical reconfiguration, the evolution of the innovation system also shows sectoral changes in patent records. As expected, *'Services'* strongly declined after the revolution, as this category covers inventions in household goods, leisure, personal care, etc., that were no longer a priority. Moreover, these fields were dominated by local professionals and businessmen who were affected by legislation against private activities or who directly abandoned the island. There was also a substitution of some heavy industries, as *'Machinery and equipment'* or *'Basic metals'*, by other sectors closer to basic consumption, such as *'Agriculture and cattle farming'*. However, the share of registered patents in the pharmaceutical sector increased from 10.32% in 1947-1952 to 29.39% in 1959-1964 (26.45% in 1965-1970), a rise that may reflect the new government's growing interest in healthcare, drug supplies, and the training of doctors and researchers. If combined with *'Other Chemicals'*, the progression in this sector is outstanding, reaching almost half of all registered patents from 1959 to 1970. This lends support to our second hypothesis, regarding the continued role of the chemical and pharmaceutical industries after the revolution. The legacy of the early U.S. presence—which brought into the island facilities and doctors to produce generic drugs and medicines such as tetracyclines, steroids, and antibiotics—together with the increasing presence of pharmaceutical firms from European countries and local developments such as those from the *Instituto Biológico Cubano*—intervened by the state in 1959 and ultimately nationalized in 1962 (Ravenet Ramírez, 2024)—underlines a path-dependent trajectory that still influences the Cuban NIS today (Cárdenas O'Farrill, 2009; Perez Villanueva and Albizu-Campos Espiñeira, 2023; Recarte, 1980; World Health Organization et al., 2015).

During the *Post-Revolutionary* period (1965-1976), the sectoral analysis highlights an emerging technological divergence related to the interests of the Cuban government, as also hypothesized in Section 3.1. Government pressures led to the growth of invention activities in sectors such as '*Agriculture and cattle farming*', '*Machinery and equipment*', and notably, the resurgence of the '*Sugar*' industry. Cuba began to yield significant increases in sugar production (with a peak of 8.5 million tons in 1970) to fulfill contracts with the USSR (which purchased sugar at a fixed price to support the Cuban government) and other countries such as Spain or Japan (with commercial agreements centered around sugar) (Pollitt, 2004), explaining the increase innovation within this sector. Nevertheless, '*Pharmaceuticals*' and '*Other Chemicals*' still maintained a predominant position, supported by the aforementioned clear emphasis of the revolutionary government on improving healthcare conditions across the island. During these years, they achieved a decline in contagious diseases (from over two thousand deaths per year in 1959 to less than two hundred a year in 1969) and an increase in the number of doctors and medical professionals trained on the island.[21]

Finally, as patent activity dropped significantly after 1962 (see Fig. 1), we calculated the levels of patent concentration among the top five actors within the three main sectors in each period studied. Between 1947 and 1952, the most important U.S. companies accounted for 17% of patents in both '*Pharmaceuticals*' and '*Other Chemicals*', figures that decreased to 14% and 8% respectively between 1953 and 1958. However, from 1965 to 1970, top non-U.S. companies accounted for 30% of patents in '*Other Chemicals*' and 16% in '*Pharmaceuticals*', while between 1971 and 1976 top Cuban institutions accounted for 9% of patents in '*Sugar*', 6% in '*Other Chemicals*', and 8% in '*Agriculture and Cattle Farming*'. In this last sector and period, for instance, British companies accounted for 11% of patents. Thus, although Cuban institutions were in the central components of the network in the 1970s (see Fig. 3), they did not fully dominate patent activity, as there were small and medium components formed mainly by innovators from non-U.S. countries (see Fig. 2) still filing patents.

4.5. The geography of collaboration on the island

Regarding network openness and international interactions, the analysis shows that the complex interplay between the capitalist and socialist worlds was one of the main factors influencing the evolution of the innovation system on the island. The domestic tensions were exacerbated by the geopolitical reality of the Cold War, which also left its mark on the foreign connectivity of the Cuban patent network. By analyzing the patentees/inventors' place of residence and how firms, scientists, and technicians from different countries collaborated, we explore the scope and evolution of transnational knowledge transfer in Cuba (Fleming and Waguespack, 2007; Montobbio and Sterzi, 2013; Picci, 2010). In doing so, we not only analyze the distribution of clusters by the residence of their members but also discern between two possible patterns of cooperation: foreign companies linking with local inventors (*reaching-in*) or the opposite, Cuban firms seeking foreign knowledge (*reaching-out*) (Berman et al., 2020).[22] The different directionality between collaboration patterns is significant for innovation analysis because *reaching-in* processes can lead to the development of local expertise and integration into global innovation systems. This is particularly relevant in the context of challenging structural transformations, where higher levels of knowledge enhance absorptive capacities (Castellacci and Natera, 2016; Li and Du, 2025). However, as had been traditionally the case in the Cuban economy, *reaching-in* interactions could also foster dependency on foreign entities. On the other hand, *reaching-out* processes indicate a local entity's ability to connect with and utilize global knowledge networks, promoting self-reliance and international collaboration.

Table 5 presents the geographical distribution of the clusters in the network across the time windows of study. Besides a decline in the number of total clusters due to network attrition, as shown in the last row, the data also indicate that network homophily—the tendency of nodes to associate and bond with similar others (those of the same residence in our case)—always predominated. This principle, often summarized in the SNA literature by '*birds of a feather flock together*', plays a significant role in the formation and evolution of networks (Au, 2023; Leszczensky and Pink, 2015; McPherson et al., 2001). In the context of innovation networks, homophily can both facilitate and hinder the diffusion of new ideas and technologies. While homophilous relationships can enhance trust and cooperation among network members—fostering collaboration and knowledge sharing—immoderate homophily can limit exposure to diverse perspectives, reducing creativity and innovation (Rogers, 1983).

Thus, the results corroborate our fourth hypothesis in Section 3.1—regarding the level and evolution of international collaboration—and demonstrate that the Cuban patent network exhibited a high degree of geographical homophily across the periods under study. Before the revolution, over 80% of the components found on the island were composed of innovators with the same country of residence. This tendency intensified, increasing from 84.3% during 1947-1952 to 95% from 1965 onwards. During the *Pre-Revolutionary* period, approximately 43% of the components were formed by U.S. patentees and inventors, reflecting a significant prevalence of U.S.-originated technology transfers. Their patents served to protect either direct investments on the island or the commercialization of new products and processes, mainly in the pharmaceutical/chemical sector. This trend began to shift during the *Revolutionary* period—when

[21] According to Recarte (1980, pp. 127–128), this medical training served two-fold: firstly, to enhance healthcare conditions for the most disadvantaged population on the island, and secondly, to send doctors to other developing countries, thereby earning an international reputation (i.e. '*health diplomacy*') while improving the balance of payments through remittances from these workers.

[22] This analysis is possible because, besides the actors' place of residence, we also have the role they play in the patent (assignee, inventor, or assignee/inventor).

components composed entirely of members from third countries surpassed those associated with the United States—and culminated in the *Post-Revolutionary* period—during which more than two-thirds of the components were formed, mainly, by European patentees and inventors. This reflects a broader process of substituting technological dependence on the United States with reliance on European countries, including those within the Soviet sphere. Finally, components formed exclusively by Cuban firms and inventors declined from a peak of 22% in the initial period to approximately 10% after the revolution, before rising to 18% in the last time window—indicating the emerging role of public institutions and universities in the Cuban NIS. Therefore, the analysis illustrates how the institutional shock caused by the revolution prompted a structural change that caused a loss in network openness and knowledge-sharing opportunities.

In terms of international collaboration, a clear shift in network dynamics arises when studying the scarce non-homophilic components of the network, i.e., cross-country collaboration. Before 1959, a small proportion of patent clusters (under 2%) reflected collaborative relationships between Cuban and U.S. innovators. These clusters had predominantly a *reaching-in* nature, meaning that U.S. companies employed Cuban inventors, facilitating an exchange of knowledge and ideas between Cuba and the United States—a valuable asset for international knowledge flow on the island. We also find several *reaching-out* clusters formed by Cuban firms collaborating with innovators from other nationalities (excluding the U.S.). These companies actively collaborated with foreign inventors to register patents on the island, signaling a proactive approach by local entities to engage with international partners, thus fostering innovation through diverse and global perspectives.

However, after the revolution, all clusters involving 'Cuba + U.S.' actors disappeared and the few remaining international relationships involved only two countries within the socialist sphere—the USSR and Bulgaria. Those relations were characterized by *reaching-out* dynamics, whereby Cuban firms sought to access foreign knowledge and expertise rather than contribute to it, underscoring a paradigmatic realignment in Cuba's patent network, moving from a model that integrated Cuban inventors into broader U.S. initiatives to one where Cuba engaged selectively with international partners, specifically within a socialist alliance. These findings are consistent with other studies on scientific collaboration (as measured by article co-authorship) during the same periods, which demonstrate that U.S.-Cuba links predominated before 1959 and were then completely replaced by European collaborations between 1960 and 1980 (Guzmán-Sánchez et al., 2018, p. 1540; Ronda-Pupo, 2021; Fig. 3).

Therefore, the increase in geographical homophily in the *Post-Revolutionary* period evidences the reduction of technological openness and the contraction of the international patent linkages of the country during the 1960s and the first years of the 1970s. This demonstrates how structural and institutional transformations can significantly alter the dynamics of these kinds of networks, which can reshape the geography of innovation and also impact the absorptive capacities of local nodes. However, state-led initiatives and the research efforts concentrated in certain sectors (biotechnology) seem to have reversed this tendency in recent decades, as suggested by the latest analyses of Cuban patents granted in the U.S., which indicate higher rates of openness (connections to foreign nodes) and growing absorptive capacities of Cuban inventors in comparison with other Latin American countries (Bianchi et al., 2023).

5. Conclusions

Cuba represents a striking paradox: despite its proven ability to develop innovative and highly effective COVID-19 vaccines (Yaffe, 2021), the country still grapples with chronic power blackouts and good shortages. While scientific conglomerates such as *BioCubaFarma* are capable of producing and exporting technological advances at the frontier of knowledge and even registering patents in the United States (Guzmán-Sánchez et al., 2018; Perez Villanueva and Albizu-Campos Espiñeira, 2023), the greater part of the Cuban economy is languishing in an unsustainable manner. How can such technological achievements coexist with fundamental economic and institutional weaknesses? This contradiction illustrates the dual nature of resilience in structurally constrained systems, where native and targeted innovation can thrive even as broader vulnerabilities remain. In a world increasingly affected by institutional fragility and geopolitical shocks, the Cuban case provides a valuable setting to explore innovation under conditions of structural change.

This research presents a novel approach to empirically studying these processes. The 1959 revolution marked a pivotal juncture in Cuban—and, arguably, American—history and economy, becoming one of the few countries that replaced a capitalist economic regime with a socialist model that endures today. This offers insights into how political, economic, and institutional restructuring reshapes innovation trajectories. To investigate it, we compiled a comprehensive dataset of patents registered in Cuba between 1947 and 1976. Using SNA, we map the evolution of the country's co-patent network before and after the revolution. The results reveal that before the revolution, the size and connectivity of the Cuban network increased, although it was always dominated by the U.S. presence. This evolution led to a mature, albeit homophilic, network centered in a few large clusters around specific activities such as pharmaceuticals and other chemicals. This focus

Table 5
Cluster analysis by their members' country of residence, Cuba (1947-1976).

	Pre-Revolutionary Period		*Revolutionary* Period	*Post-Revolutionary* Period	
Residence of members	*1947-1952*	*1953-1958*	*1959-1964*	*1965-1970*	*1971-1976*
All from *United States*	42.91%	43.87%	38.18%	9.57%	9.01%
All from *Cuba*	21.99%	21.07%	9.39%	10.43%	18.02%
All from *Other Countries*	19.68%	22.68%	40.00%	74.78%	66.67%
Cuba + U.S.	1.42%	1.86%	1.21%	-	-
—reaching-in	*75%*	*60%*	*75%*	-	-
—reaching-out	*25%*	*40%*	*25%*	-	-
Cuba + Other Countries (exc. U.S.)	2.13%	1.12%	0.61%	-	5.41%
—reaching-in	*33%*	*33%*	*100%*	-	*0%*
—reaching-out	*67%*	*67%*	*0%*	-	*100%*
U.S. + Other Countries (exc. Cuba)	11.52%	8.55%	10.30%	5.22%	0.90%
Cuba + U.S. + Other Countries	0.35%	0.87%	0.30%	-	-
—reaching-in	*100%*	*100%*	*100%*	-	-
—reaching-out	*0%*	*0%*	*0%*	-	-
Number of Clusters	*564*	*807*	*330*	*115*	*111*

Source: Computed from the network dataset.

mainly reflected the objectives of U.S. companies in Cuba, trying to solve the prevalence of tropical diseases and the need for generic drugs on the island. The Cuban Revolution of 1959 introduced a radical shift, dismantling the pre-existing patent network structure, and reshaping IPRs and their associated economic incentives.

After 1959, the Cuban network underwent significant changes, characterized by a notable reduction in patent registrations combined with an increase in connectivity among the most resilient remaining nodes. The departure *en masse* of U.S. companies and inventors, combined with the local brain drain and the U.S. trade embargo, diminished the island's human capital and, therefore, Cuban absorptive capacities. Nevertheless, certain U.S.-based firms managed to maintain patent activity on the island through mechanisms beyond sheer size, leveraging their capacity for regulatory influence and adaptive strategies to mitigate embargo restrictions (e.g., the *American Cyanamid Company*). This underscores the strength that large, resource-rich corporations can demonstrate even under stringent political barriers. Moreover, between 1959 and 1964, some of those U.S. companies often occupied leading roles within the network, suggesting that lobbying capacities and strategic adaptability allowed them to sustain operations in adverse circumstances.[23] This phenomenon contributes to today's relevant debate about the knowledge-intensive economy, where corporate capitalism often surpasses state capacities in regulating and directing innovation trajectories (Reich, 2020; Rikap, 2024).

Notwithstanding this resilience, attrition dynamics intensified over time, with a further contraction in the number of registered patents and in key topological measures of the network, which evolved into a smaller but more interconnected one. In this context, the analysis reveals two paths of network change after the revolution: on the one hand, the island experienced a shift in the composition of patenting actors towards public institutions such as the *Universidad de la Habana* and the *Centro Nacional de Investigaciones Científicas*, which promoted several local invention activities and demonstrated the success of public policies aimed at enhancing education and research. Furthermore, the needs of the new government prompted the creation of institutions such as the *Ministerio del Azúcar* in 1964 (Leal del Ojo de la Cruz, 2023), which led to significant increases in sugar production and fostered innovation within the sector, centered around local institutions and inventors. As a result, the sugar industry became a focal point for national technological advancement and self-sufficiency. Meanwhile, individual and private initiatives practically disappeared from the patent system, as evidenced by the number of isolate patentees and inventors shown in Table 3.

On the other hand, the former large U.S. corporations were progressively replaced by companies from other countries, such as the Swiss *Hoffmann-LaRoche & Co. A. G.* and the German *Farbenfabriken Bayer, A. G.*, which also concentrated primarily on the pharmaceutical sector. The extensive capital stock and know-how accumulated during years of U.S. influence—alongside local initiatives such as those of the *Instituto Biológico Cubano*—were leveraged by the revolutionary government, which implemented numerous public policies aimed at improving healthcare on the island and fostering national development. The combination of foreign and domestic expertise enabled the pharmaceutical sector to develop innovative medical solutions gradually, such as the world's first meningitis B vaccine in the 1980s (Starr, 2004), establishing Cuba as a pharmaceutical *power player* in Latin America (Cárdenas O'Farrill, 2009; Thorsteinsdóttir et al., 2004). This legacy of biomedical innovation has continued even in the face of increasingly unsustainable economic conditions, as evidenced by the increasing value of Cuba's biotechnology exports (Perez Villanueva and Albizu-Campos Espiñeira, 2023; Fig. 1).

The analysis of the evolution of the Cuban NIS also provides context to ongoing debates on structural change and innovation dynamics—particularly within Latin America, the Caribbean, and other developing regions—in several significant ways. First, our work shows that strong public intervention can decisively shape the trajectory of a patent network, including the radical transformation of its topology. Although state-owned enterprises and public institutions can achieve innovation outcomes comparable to those of private firms (Castelnovo, 2022; Lin et al., 2021), the systemic effects of network restructuring on individual behavior and incentives warrant caution, particularly in the context of contemporary populist political decisions that impact science, technology, and education—even in leading economies.

Second, the study illustrates how IPR regimes, even in predominantly state-led economies, can function as active instruments of innovation governance rather than mere legal formalities. The strategic weakening of IPRs to promote industrialization and technological development has been a common practice among lagging countries in the past, yielding mixed outcomes (Bondarev, 2018; Moser, 2012). In the Latin American context, some scholars argue that this practice tends to reduce foreign investment (Viglioni et al., 2023). In the Cuban case, as previously discussed, the more socialist-oriented IPR practices after the revolution—together with other factors such as the geopolitical rupture with the United States—initially contributed to undermining the patent network. Nevertheless, contrary to other socialist countries, Cuba always maintained its patent system, using it strategically to sign agreements with Western companies and to protect the research outputs of public institutions, a role that became increasingly significant, especially with the rise of the biotechnology sector in the late twentieth century. Moreover, since the mid-1990s, Cuba has progressively reintroduced IPR reforms to promote patent commercialization abroad and establish individual incentives that reconcile state ownership with scientific productivity, ultimately allowing inventors to participate in patent exploitation (Perez Villanueva and Albizu-Campos Espiñeira, 2023).[24]

Third, our investigation calls for further research on the consequences of public design of innovation targets—such as pharmaceuticals and, later, biotechnology—because success concentrated in a single sector may be insufficient to catalyze a broader process of technological development over the long term. Consequently, as the Cuban case readily illustrates today, such sectoral achievements may coexist with persistent economic stagnation, a poverty trap that, for some scholars, would not be overcome without massive inflows of external aid (López-García et al., 2011) and, for others, without internal economic and political liberalization (Corrales, 2012). Fourth, the Cuban experience also suggests that, after the revolution, the rise of geographical homophily, the reduction in network openness, and the loss of both local and foreign human capital significantly weakened the absorptive capacities within the patent system during the 1960s and 1970s—which could be a critical factor in reorienting technological development under structural constraints (Castellacci and Natera, 2016; Li and Du, 2025). Knowledge integration capacities are closely linked to international collaboration, which—as shown by other studies on Cuban scientific performance—has resurged in Cuba since the 1990s, particularly within the biotechnological sector (Bianchi et al., 2023; Guzmán-Sánchez et al., 2018). International biomedical collaboration has grown markedly, not only with European and Latin American partners but also with U.S. scholars and institutions, despite persistent political constraints.

Consequently, our analysis also underscores the powerful influence of geopolitics on the evolution of NIS (Chatterji and Murray, 2025; Góes and Bekkers, 2022). The Cuban innovation system—and indeed the country's broader historical trajectory—cannot be fully understood without accounting for its complex and often contentious interactions with the United States and, later, alignment and economic dependency on the Soviet Union (Gao et al., 2024). Caught between these two

[23] Even in recent times (1997–2008), despite the trade embargo and ongoing geopolitical conflicts, the United States has remained the foreign country with the highest number of patent registrations in Cuba (Díaz Pérez et al., 2018).

[24] See the IPR legislative changes mentioned in footnote 9.

geopolitical dependencies, and subject to persistent diplomatic tensions and the enduring U.S. trade embargo, Cuba's revolutionary path has led to a complex international position. Beyond our findings, the frontal and long-term clash between the Cuban and U.S. governments—recently intensified—has narrowed the possibilities of cooperation and represents the worst-case scenario, especially for the island, though not exclusively so. In fact, during the Obama administration a *Nature* editorial argued that the *"United States would do well to end restrictions on collaborations with the island nation's scientists … As the global centre of biotech, and with some of its marine ecosystems contiguous with Cuba's, the United States is surely the country with which cross-fertilization of ideas makes the most sense"* (Nature, 2009); a position that has been continuously advocated among researchers in other key journals such as *Science* (Fink et al., 2014).

Unfortunately, such claims about the benefits of increasing collaboration—one of the central themes of this study—remain largely absent from today's global discourse. Yet, disruptions and shocks will continue to affect innovation systems and challenge the foundations of cooperation. From the perspectives of network theory and innovation management, a key historical lesson emerging from the analysis of the topological evolution of the Cuban patent network is the need to balance large, well-established research hubs with smaller, more flexible innovation actors. Highly centralized systems, whether in energy infrastructure or research contexts, often struggle to adapt to major perturbations. In contrast, resilient innovation networks tend to integrate stable institutional frameworks with independent and dynamic entrepreneurial components capable of responding swiftly to changing conditions. More broadly: fostering collaboration between public research institutions and private startups, facilitating technology transfer, and promoting international partnerships could help build a more adaptive, innovative ecosystem—one better prepared to face the inevitable shocks, of any kind, that sooner or later will arise.

CRediT authorship contribution statement

Sergio Barbosa: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Data curation, Conceptualization. **Patricio Sáiz:** Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **José L. Zofío:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Database construction details

BOMC 1949

BOLETIN OFICIAL DEL MINISTERIO DE COMERCIO

REPUBLICA DE CUBA

MINISTERIO DE COMERCIO

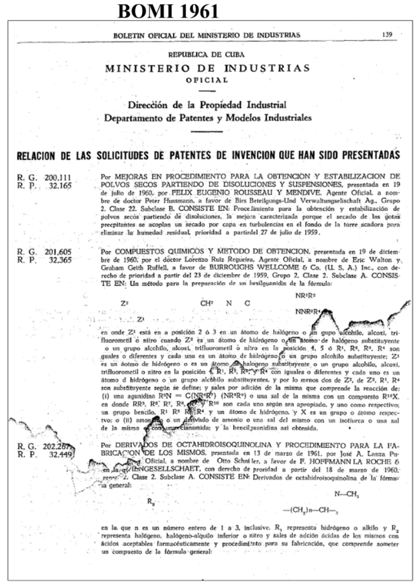
OFICIAL

Dirección de la Propiedad Industrial

Negociado de Patentes y Modelos Industriales

RELACION DE LAS SOLICITUDES DE PATENTES DE INVENCION QUE HAN SIDO PRESENTADAS:

BOMI 1961



BOLETIN OFICIAL DEL MINISTERIO DE INDUSTRIAS 139

REPUBLICA DE CUBA

MINISTERIO DE INDUSTRIAS

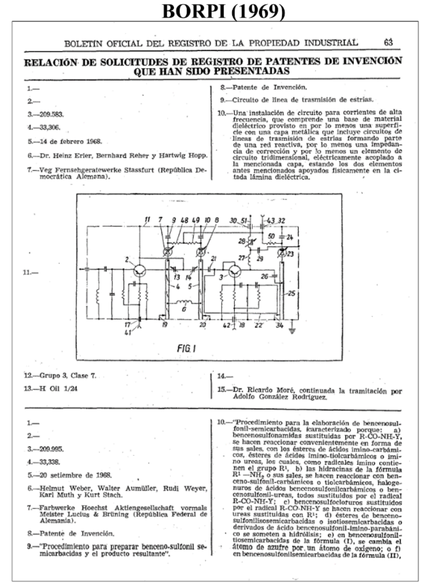
OFICIAL

Dirección de la Propiedad Industrial

Departamento de Patentes y Modelos Industriales

RELACION DE LAS SOLICITUDES DE PATENTES DE INVENCION QUE HAN SIDO PRESENTADAS

BORPI (1969)



BOLETIN OFICIAL DEL REGISTRO DE LA PROPIEDAD INDUSTRIAL 63

RELACIÓN DE SOLICITUDES DE REGISTRO DE PATENTES DE INVENCIÓN QUE HAN SIDO PRESENTADAS

Fig. A1. Examples of the Cuban Boletín Oficial del Ministerio de Comercio (later Boletín Oficial del Ministerio de Industrias; Boletín Oficial del Ministerio de la Industria Básica; and Boletín Oficial del Registro de la Propiedad Industrial).
Source: *OCPI* and *OEPM*.

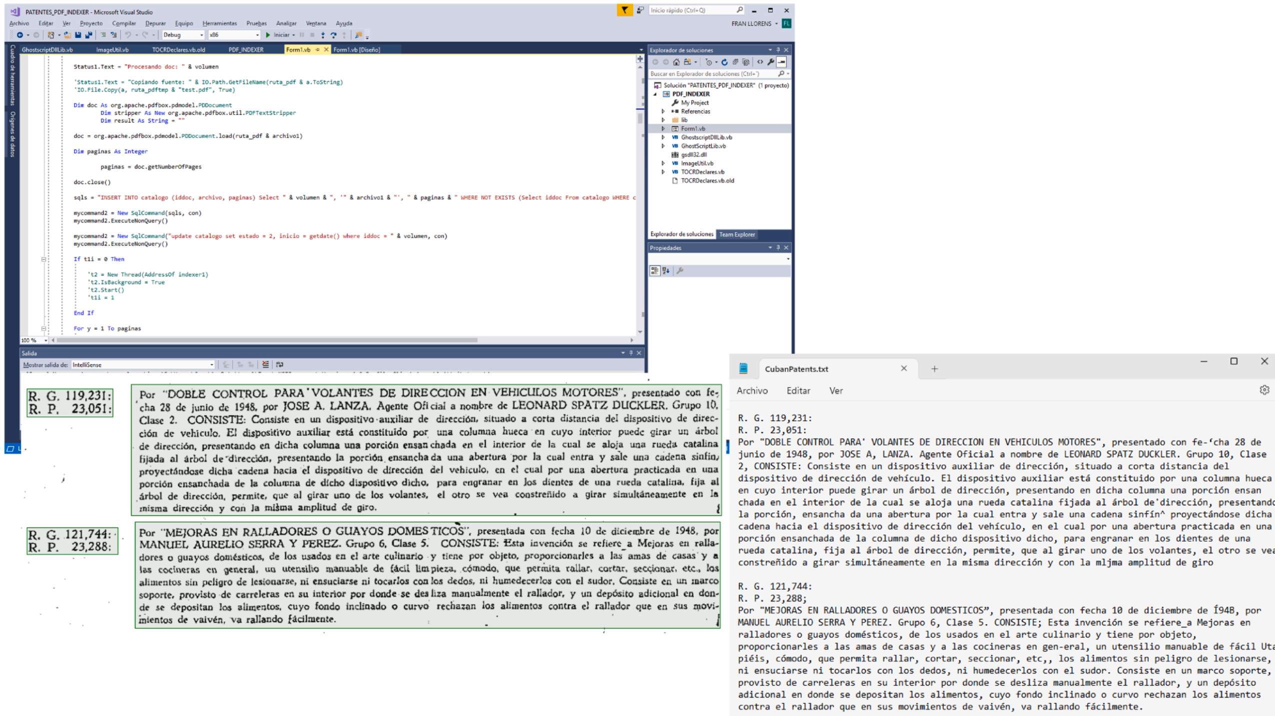


Fig. A2. Image-processing script of the Cuban gazettes for text extraction and indexation. Examples of OCR results.
Source: Own elaboration.

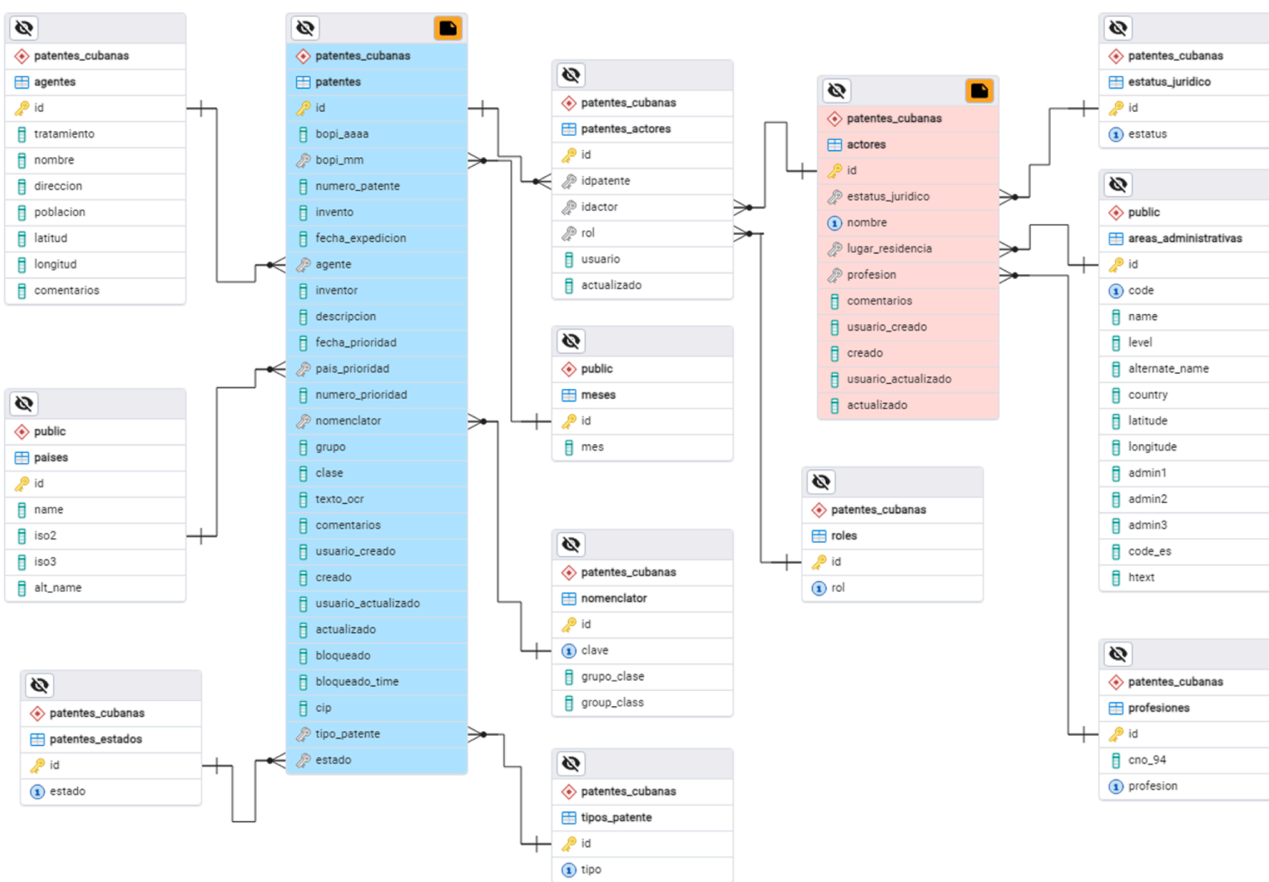


Fig. A3. Basic entity-relationship model of the Cuban patent database (1946-1979).
Source: Own elaboration.

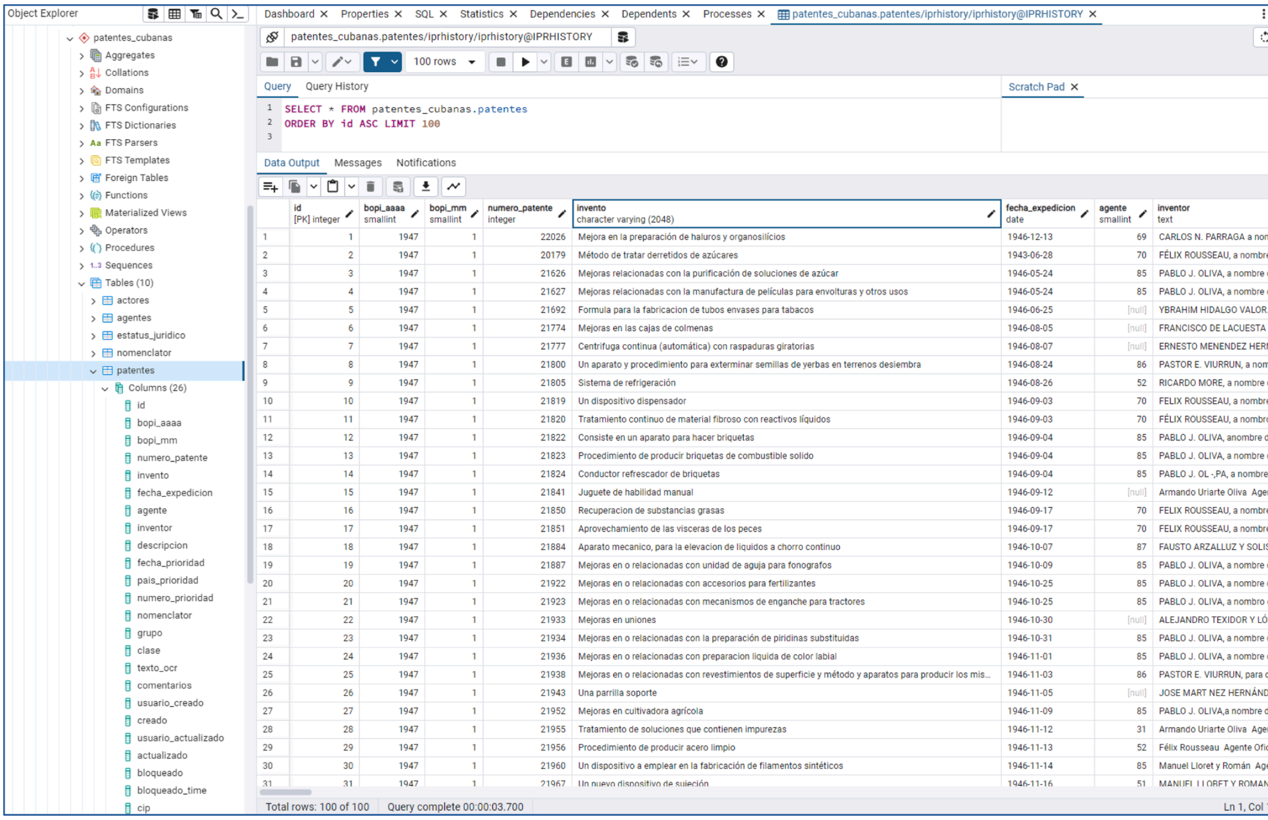


Fig. A4. The Cuban patent database (1946-1979) in a PostgreSQL instance.
Source: Own elaboration.

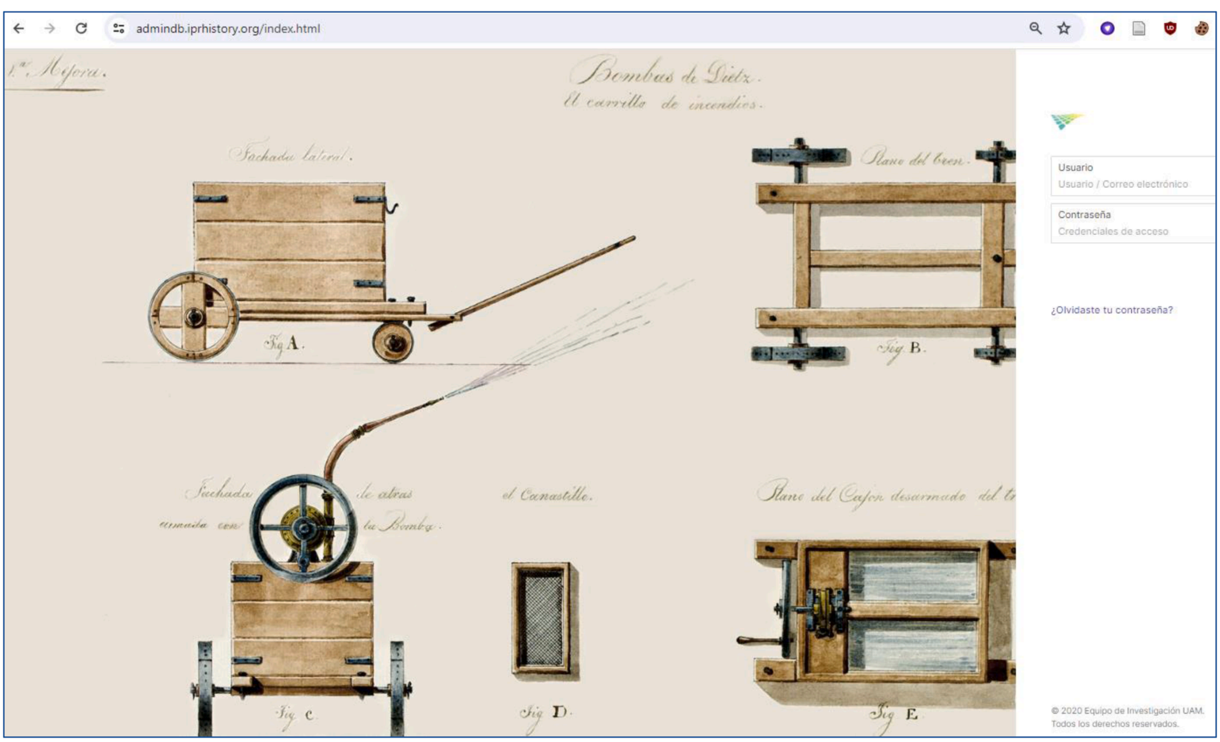


Fig. A5. Web platform designed for real-time and simultaneous edition and improvement of the Cuban patent database (1946-1979).
Source: Own elaboration.

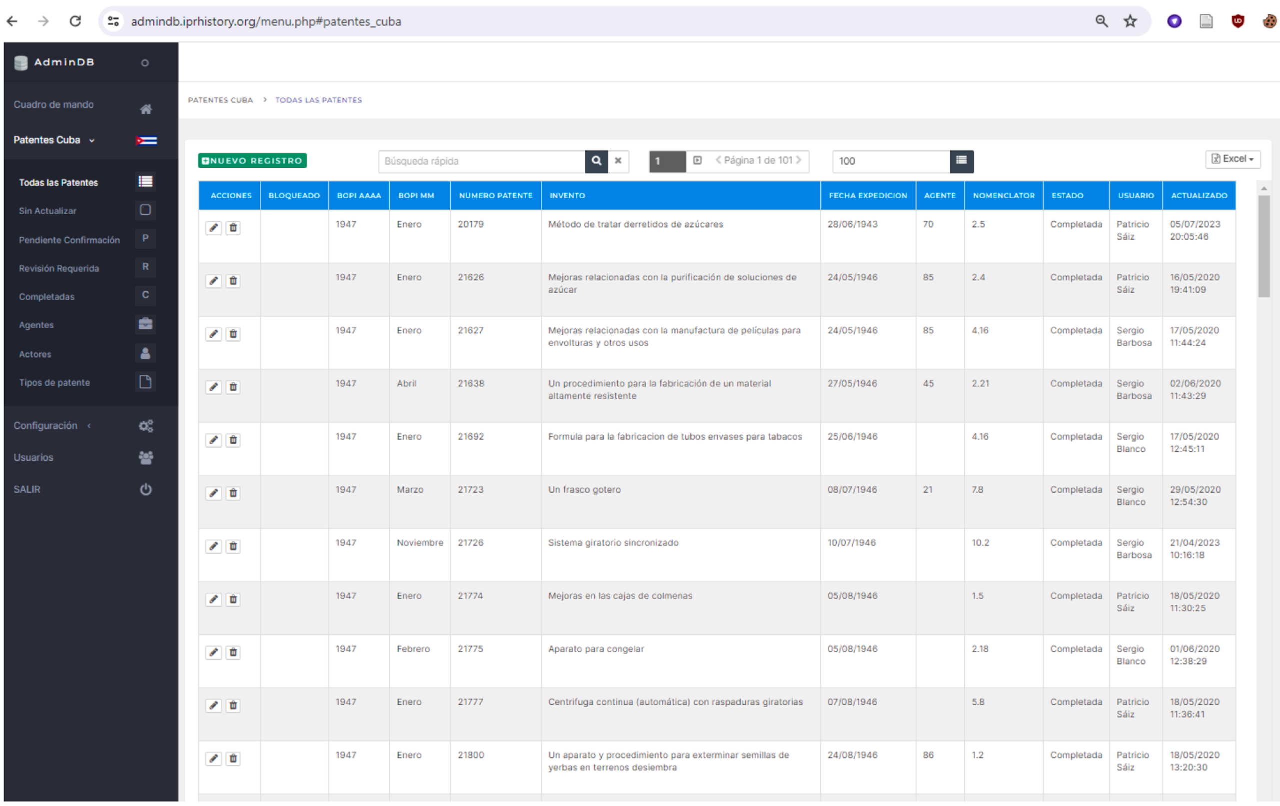


Fig. A6. Web interface for the Cuban database (1946-1979) management system.
Source: Own elaboration.

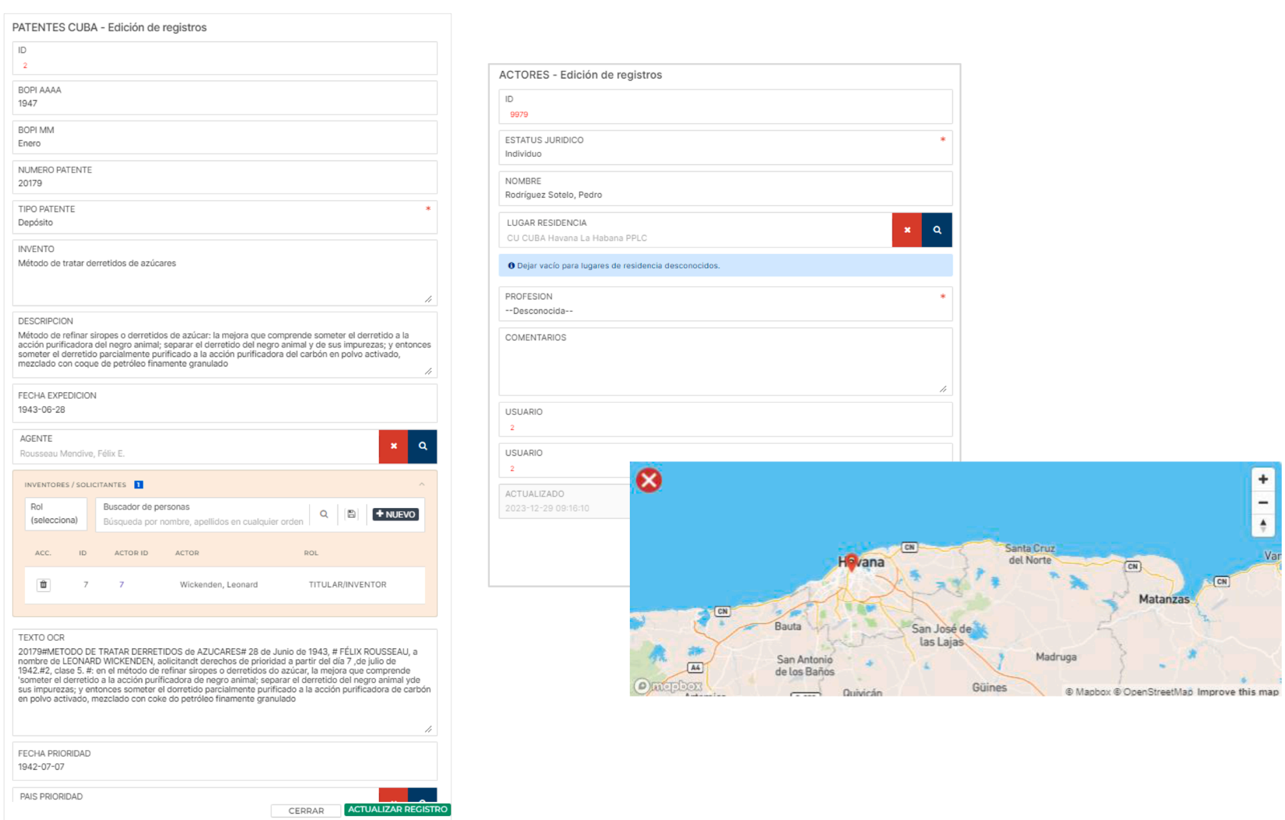


Fig. A7. Examples of online edition of Cuban patents (1946-1979), including the geopositioning of inventors and assignees through Geonames geographical database, complemented with automatic map search.
Source: Own elaboration.

Nomenclator

Artículo 92.—Para la clasificación de las materias a que se refieren las patentes regulalas por este Decreto-Ley y para la formación de índices y catálogos regirá el siguiente nomenclator dividido en once grupos, subdivididos cada uno en diferentes clases que podrán ampliarse o disminuirse según las necesidades de las diferentes materias que lo reclamen:

PRIMER GRUPO

Agricultura

Clase 1.—Mejoras en terrenos y de plantaciones. Cultivo. Abonos.
Clase 2.—Aperos e instrumentos de labranza. Máquinas agrícolas.
Clase 3.—Horticultura y jardinería. Insenticidas y aparatos diversos para exterminar animales nocivos.
Clase 4.—Explotaciones agrícolas y forestales.
Clase 5.—Ganadería. Forrajes y alimentos para el ganado. Veterinaria. Carnicerías. Mataderos. Establos. Abrevaderos. Herraduras. Yugos. Prensa yugos. Avicultura. Apicultura.
Clase 6.—Caña, Siembra, Cultivo.
Clase 7.—Aparatos. Máquinas. Útiles y artefactos usados en el corte y transporte de la caña con excepción de trasbordadores y accesorios para los mismos.
Clase 8.—Trasbordadores de caña, trasbordadores básculas y accesorios para los mismos.
Clase 9.—Tabaco. Siembra. Cultivo. Manufactura.
Clase 10.—Tratamiento del tabaco en rama, excepto máquinas para torcer tabaco.

SEGUNDO GRUPO

Industrias Químicas

Clase 1.—Galletería. Panificación. Levaduras. Féculas. Almidones. Dextrinas y glucosas. Celulosas.
Clase 2.—Productos y procedimientos farmacéuticos.
Clase 3.—Fabricación del azúcar. Procedimiento, máquinas, aparatos y productos para la extracción del jugo de la caña de azúcar.
Clase 4.—Fabricación del azúcar. Purificación, defecación y clarificación del jugo de la caña de azúcar.

Clave	Grupo_Clase
1	Agricultura
1,1	Clase 1.—Mejoras en terrenos y de plantaciones. Cultivo. Abonos.
1,2	Clase 2.—Aperos e instrumentos de labranza. Máquinas agrícolas.
1,3	Clase 3.—Horticultura y jardinería. Insecticidas y aparatos diversos para exterminar animales nocivos.
1,4	Clase 4.—Explotaciones agrícolas y forestales.
1,5	Clase 5.—Ganadería. Forrajes y alimentos para el ganado. Veterinaria. Carnicerías. Mataderos. Establos. Abrevaderos
1,6	Clase 6.—Caña, Siembra, Cultivo.
1,7	Clase 7.—Aparatos. Máquinas. Útiles y artefactos usados en el corte y transporte de la caña con excepción de trasbor
1,8	Clase 8.—Trasbordadores de caña, trasbordadores básculas y accesorios para los mismos
1,9	Clase 9.—Tabaco. Siembra. Cultivo. Manufactura.
1.10	Clase 10.—Tratamiento del tabaco en rama, excepto máquinas para torcer tabaco.
2	Industrias Químicas
2,1	Clase 1.—Galletería. Panificación. Levaduras, féculas. Almidones. Dextrinas y glucosas. Celulosas.
2,2	Clase 2 —Productos y procedimientos farmacéuticos.
2,3	Clase 3.—Fabricación del azúcar. Procedimiento, máquinas, aparatos y productos para la extracción del jugo de la caí
2,4	Clase 4.—Fabricación del azúcar. Purificación, defecación y clarificación del jugo de la caña de azúcar.
2,5	Clase 5.—Fabricación del azúcar. Filtración de los jugos de la caña de azúcar.
2,6	Clase 6—Fabricación del azúcar. Evaporación y cristalización de los jugos de la caña de azúcar.
2,7	Clase 7.—Fabricación del azúcar. Purga y desecación del azúcar.
2,8	Clase 8.—Fabricación del azúcar. Refinación del azúcar.
2,9	Clase 9.—Vinos. Sidras. Cervezas. Vinagres.
2.10	Clase 10—Destilería. Alcoholes. Aguardientes. Licores.
2.11.	Clase 11.—Aceites de origen orgánico. Grasas. Jabones. Bujías. Fósforos. Cerería. Dentífricos. Cosméticos. Perfumerí
2.12.	Clase 12.—Gomas. Resinas. Caucho. Gutapercha. Barnices. Hules. Linóleo. Charoles. Cueros. Pieles. Curtidos. Corre
2.13,	Clase 13,—Destilación de leñas. Conservación de maderas. Papel de todas clases. Papel de fumar. Cartones.
2.14.	Clase 14.—Albúminas. Gelatinas. Colas. Celuloides y su industria. Fabri·cación de la cera artificial o viscosa.
2.15.	Clase 15.—Explosivos.
2.16.	Clase 16.—Gases para el alumbrado. Gasógenos.
2.17.	Clase 17.—Combustibles sólidos, líquidos y gaseosos. Hidrocarburos. Aglo·merados.
2.18.	Clase 18.—Purificaciones de aguas. Bebidas gaseosas. Refrescos. Hielo artifi·cial. Refrigeración. Filtración.
2.19.	Clase 19.—Colores. Materias tintóreas. Tintos. Mordientes. Esmaltes. Se·cantes. Material y utensilios para pintores.
2.20.	Clase 20.—Blanqueo. Estampado. Limpia-objetos.
2.21.	Clase 21.—Cales. Hornos de cal. Cementos. Asfaltos. Yesos, Piedra artificial.
2.22.	Clase 22.—Cerámica. Ladrillos. Tejas. Losetas. Alfarería. Loza y porcelana. Cristalería. Fabricación de Vidrios y de bote
2.23.	Clase 23.—Productos químicos naturales y artificiales.
2.24.	Clase 24.—Explotación de minas, canteras, balnearios y aguas minerales. Ex·traer, tratar, beneficiar, aglomerar, enriqu
2.25.	Clase 25.—Fusión y manipulación del hierro y del acero. Fabricación del fundido. Cubiletes. Maquinaria para moldear la
2.26.	Clase 26.—Metales diversos. Aleaciones y amalgamas. Metalización.
3	Física Industrial y Electricidad
3,1	Clase 1.—Generadores de vapor. Calderería en general. Desincrustantes. Evaporadores. Condensadores. Accesorios.
3.2	Clase 2.—Hornos. Hornos de quemar bagazos y otros accesorios de hornos (no eléctricos.) Chimeneas. Hogares. Cole
3.3	Clase 3.—Calefacción (no eléctrica). Ventilación (no eléctrica). Trata·miento y recogida de basuras. Saneamiento y de
3.4	Clase 4.—Alumbrado (no eléctrico). Mecheros y quemadores. Aparatos diversos.
3.5	Clase 5.—Pilas. Acumuladores. Para-rayos y accesorios para instalaciones eléctricas. Electrólisis.
3.6	Clase 6.—Alumbrado eléctrico. Tracción eléctrica. Lámparas eléctricas. Tu·bos luminosos con gases para el alumbrad
3.7	Clase 7.—Radiofonía en general. Telefonía y Telegrafía con hilos, por tierra y submarina, rayos Roetgen, radiogeníme
3.8	Clase 8.—Aparatos eléctricos diversos. Estufas eléctricas. Calentadores y ventiladores eléctricos, plantas eléctricas, m
4	Industrias Mecánicas

Fig. A8. Detail of the 1936 Cuban patent classification (11 groups and more than 100 classes), under effect during the period studied (1946-1979). Source: Decreto-Ley 805 de 4 de abril de 1936. Ley de propiedad industrial, Cuba.

Data availability

Data will be made available on request.

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